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A STOCHASTIC MODEL FOR INTERDEPARTMENTAL HOSPITAL TRAFFIC

A THESIS

Presented to

The Faculty of the Graduate Division

by

Humberto J. Ortega

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SUMMARY

The objective of this study was to develop a stochastic model to describe interdepartmental hospital traffic. The motivation of this study was to aid the hospital planner in his decision processes by providing a description of a phenomenon in need of additional understanding.

The study was limited to the investigation of the traffic between medical and surgical nursing units and other hospital departments. Detailed traffic frequency data were collected along with concurrent information on the patient census and nursing unit staff. The data were analyzed by determining the important departments and personnel categories as evidenced by the extent of their contribution to total traffic, by determining the relationships between traffic and the degree of care required by the patients in the unit and between traffic by the nursing unit staff and the size of the staff, and by determination of the effects of variables such as the type of patient in the unit, direction of travel, and time, on the number of trips observed. Finally, a stochastic model was developed to describe the traffic between the nursing unit and important departments by important personnel categories.

It was concluded that approximately 75 percent of the traffic is accounted for by trips between 45 percent of the departments, and that non-professional nursing personnel account for almost one-third of the total traffic. The patient census categorized by degree of care and the size of the nursing unit staff were not shown to be good predictors of traffic frequencies. Finally, it was concluded that the traffic between

the nursing unit and important departments by important personnel categories can be adequately described by a random process.

The stochastic description of traffic presented permits quantitative treatment of a number of considerations important in hospital planning and in managerial decision making. Possible applications are illustrated by examples. It is expected that the results will promote the eventual development of quantitative measures for evaluating the relative efficiencies of hospital layouts.

CHAPTER I

INTRODUCTION

One of the problems of the hospital planner is deciding which of several alternative designs is best. Such a decision would be aided by an understanding of the processes occurring inside the modern hospital. While a great number of these processes have been thoroughly described and understood, there are some processes in need of additional definition, description, and understanding. The motivation for this study is to aid the hospital planner by providing a description of one of these processes. The objective is to develop a stochastic description of interdepartmental hospital traffic.

Nature of the Problem

Smalley and Freeman state that "the primary and overriding purpose of any physical facility is to promote the attainment of objectives of the enterprise in which the facility is to be used" (1). Accordingly, the primary purpose of the hospital building is to house the activities and processes which are required in attaining the objectives of the hospital. An inspection of hospitals throughout the country will reveal a wide variety of existing building designs and departmental arrangements within the buildings. It is axiomatic that some designs must promote the attainment of the hospital's objectives better than other designs. The problem to which the present study is addressed concerns the evaluation of alternative designs to determine their relative efficiency in promoting the attainment of hospital objectives. This study is focused upon what is believed to be one of the most important factors to be considered in hospital design, interdepartmental traffic. Since planning a hospital means planning for interrelated hospital functions, the relationships among the various functions are studied on the basis of personnel traffic among the various departments.

Importance of the Problem

The United States Public Health Service (USPHS), the largest single financial supporter of hospital and health research, has specifically stated the need for the development of practical tools for the evaluation of hospital designs. In a publication outlining areas of needed research, studies, and demonstrations, the USPHS lists the following among several needs: "Evaluation and development of planning guides for the construction of physical facilities . . . . The need for improved functional design of structure for maximum efficiency . . . . Space requirements, including floor plans and traffic flow . . . ."(2).

Schaefer (3), in a publication outlining staffing guides for general hospitals, cautions the user of these guides to study carefully and review factors which may affect the staffing pattern. Among the factors listed are the plan and arrangement of the hospital and the kind, amount, and distribution of supplies and equipment. The study described herein should promote the development of tools and techniques for the evaluation of hospital designs. The results should also aid in staffing the hospital if they are combined with the time spent per trip to obtain measures for the labor time spent in interdepartmental travel.

This study also has a potential contribution in monetary savings in hospital construction and in more productive utilization of the limited supply of health personnel presently available. To understand how this might be accomplished, it is well to examine the trend in hospital investments and expenses (4). From 1946 to 1966, the value of hospital assets went from about five billion dollars to more than 26 billion dollars, an increase of more than 400 percent. During the same period, annual hospital expenses rose from about two billion dollars to more than 14 billion dollars, an increase of more than 600 percent, while the cost of living increased only 66 percent during the same period. Approximately two-thirds of these annual expenses are for wages and salaries paid hospital employees. A model describing employee traffic will not, by itself, help save a large proportion of these costs. It can, however, be combined with labor and amortization costs to generate cost indices which can be utilized in the evaluation of layouts. If this utilization yields even a small percentage saving, this saving will be a significant economic return, due to the magnitude of hospital investments and expenses.

The current shortage of health personnel also makes it imperative that means be found to improve the productivity of hospital personnel. This shortage is straining the ability of hospitals to provide the health care to which Americans are accustomed. In 1965, the Director of the American Hospital Association stated that the health manpower problem is extensive and that no other problem is more in need of definition and action (5). A number of legislative programs have been launched to meet this shortage through extensive training projects, including the Health Professions Education Assistance Act of 1963, the Nurse Training Act of

1964, the Comprehensive Health Planning and Public Health Services Amendments of 1966, and the Allied Health Professions Personnel Act of 1966. There have also been various recruitment programs by the hospital associations of several states. Notable among these are the programs in Illinois (6), Tennessee (7), and Texas (8). Even though these legislative and recruiting programs have been a step in the right direction to alleviate the health manpower problem, the shortage still exists. A by-product of the present study should be to point out areas where productivity can be increased by reducing labor time devoted to travel. Brown (9) states that the techniques of industrial engineering are useful in raising the productivity of hospital employees, but that there have not been enough applications of these techniques to the health manpower problem.

The basis of the health manpower problem may very well be, as stated by McNulty (10), that the productivity gains of hospitals have not matched the productivity gains in other areas or industries. A fact lending credibility to this assertion is that payroll expenses as a percent of total hospital expenses rose from 56 to 66 percent during the 20 years from 1946 to 1965. Studies such as the one described herein are valuable if this trend is to be stopped and reversed. This study is directly related to worker productivity in that it provides a description of a facet of non-productive work (interdepartmental traffic) which can be related to hospital design.

Specific Objectives

The overall objective is to describe the employee traffic among departments of the hospital. Specific objectives are as follows:

1. to describe the extent to which the various departments contribute to interdepartmental traffic,

2. to describe the extent to which the various types of employees contribute to interdepartmental traffic, and

3. to develop a stochastic model to describe the traffic between the departments that make the major contribution to interdepartmental traffic by the types of employees making the major contribution to the traffic.

Scope and Limitations

A study of interdepartmental traffic should logically include the interrelationships between all pairs of hospital departments. This study, however, is limited to the nursing unit and other departments as they interact with the nursing unit. There are two reasons for this study limitation. First, the nursing unit is the department in which the hospital objective, patient care, is presumably achieved. Thus, the nursing unit is likely to interact with a greater number of departments than any other department. For instance, an interaction between the nursing unit and radiology is more likely to exist than an interaction between radiology and pharmacy. A conceptual model of the nursing unit as the focal center of patient care is presented in Figure 1 to illustrate the aforementioned interactions. Second, a national study of 149 hospitals indicates that nursing salaries as a percent of total salaries have a median value of 38.9 percent (11). Since the scope of this study does not permit investigation of all departments, it is reasonable to limit it in such a fashion that a department accounting for almost two-fifths of the hospi-

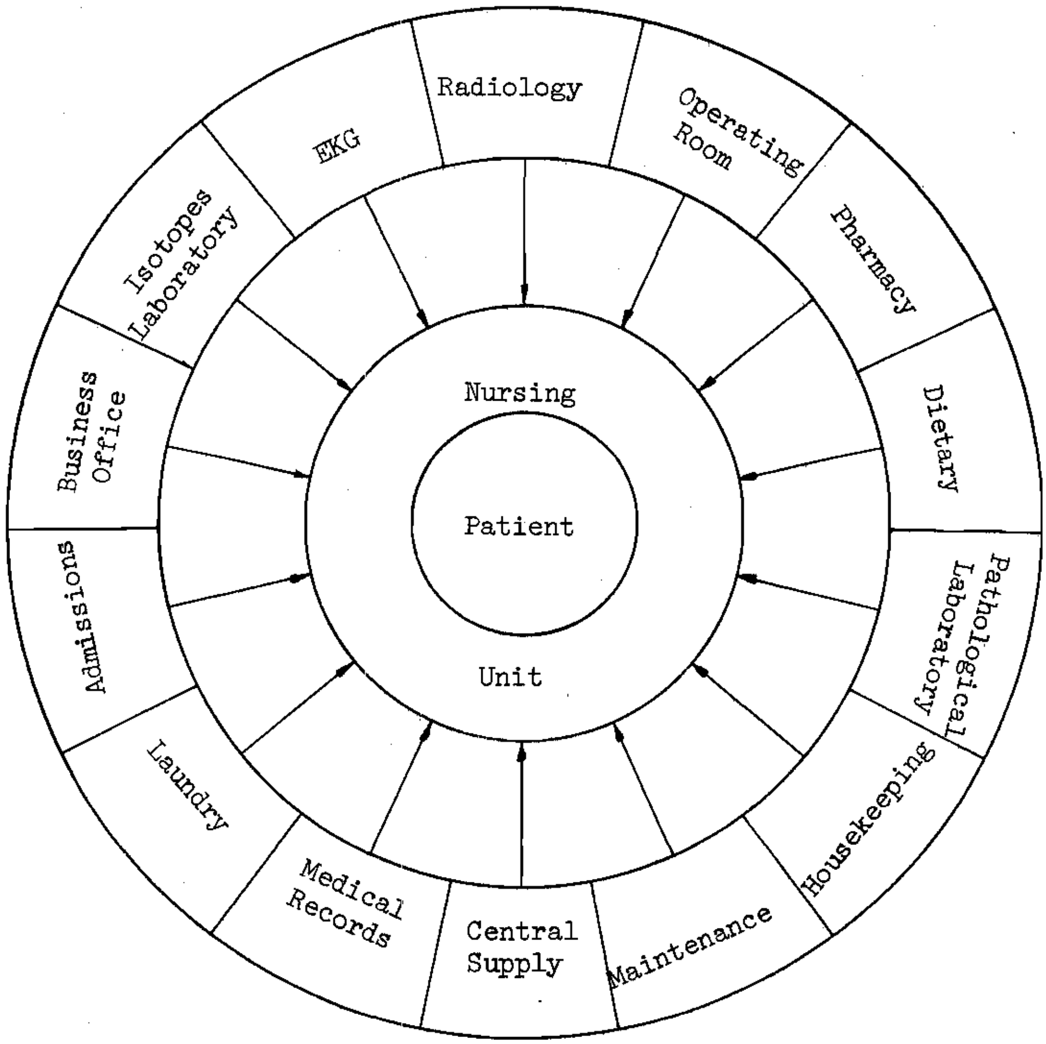

Figure 1. Conceptual Model of the Nursing Unit as Focal Center of Patient Care

tal's payroll is always considered. The results obtained from studying the traffic between the nursing unit and other departments may not be applicable to traffic among other departments. Furthermore, this study was conducted at only one hospital, and the magnitudes of the parameters of the models developed herein may require validation in other hospitals before they can be used, although it is expected that the general method of procedure will be valid in all situations.

CHAPTER II

LITERATURE SURVEY

What is possibly the first study dealing with the effects of department location upon nursing traffic and amount of work required of hospital personnel is that of Professor W. Gilman Thompson of Cornell University, his interest having been sparked by the works of Frederick W. Taylor. In an article (12) published in 1913, he praised the success of Taylor's methods in manufacturing industry and proposed that similar methods be employed in hospitals to alleviate the amount of non-productive work performed by health personnel. He described the results of several of his studies in which he had the nurses wear pedometers to record the mileage walked in performing various duties, and attempted to improve their lot by adopting work saving devices.

During the first four decades of the century there was very little interest in planning the hospital to accommodate the employee traffic. With the establishment of the National Hospital Program of the United States Public Health Service in 1946, more emphasis was placed on the advanced design of hospitals. The results of research conducted by the Division of Hospital Facilities of the USPHS were begun to be published in the hospital literature in 1946 and 1947. In one of the earlier articles (13), mention is made of the need to consider several traffic streams which should be kept separate, such as incoming patients, outgoing patients, interdepartmental patient traffic, deceased patients, visitors, medical staff, outpatients, employees, and supplies, food, and wastes. It was stated that orderly internal traffic is facilitated by correctly relating facilities and services, but that no rigid suggestions could be given in isolating these streams, except that they must be kept under constant consideration in laying out areas. While this was a significant improvement, the need for quantification is obvious.

One of the first quantitative studies of the effects of design and facilities in the patterns of work of health personnel was conducted by the Nuffield Provincial Hospitals Trust in England in 1955 (14). Studies were made "of the actual point-to-point sequence of nurses' movements in ward units" of three hospitals "from the point of view of the use of space and provision of ancillary rooms and services." In analyzing the trips, the nursing unit was considered to be comprised of two elements: the beds, and the ancillary rooms and services, of which the three most important were the kitchen and the dirty utility and clean utility rooms. The trips were divided into three groups: trips between the bed area, trips between the bed area and an ancillary room, and trips between two ancillary rooms. The most important result from this study is that, despite differences in the layout of the nursing unit in each of the three hospitals, the distribution of the three types of trips made in them was similar. These results have implications for the present study in terms of the applicability of the traffic model developed herein to another institution with similar services but with a different layout.

In 1955 George and Kuehn (15) reported the results of a study directed toward achieving a more effective utilization of nursing personnel, dealing in detail with the distribution of work among the various types of nursing tasks in a medical-surgical ward at the Woman's Hospital at Pittsburgh Medical Center. It did not include any consideration of traffic patterns in the resulting work distribution, nor the stochastic aspects of this distribution.

A significant contribution to the area of evaluation of functional efficiency was made by Pelletier and Thompson (16) in 1960. They identified sixteen areas on a typical nursing unit and recorded the number of trips between each pair of areas, each pair being referred to as a link. The weights, or relative frequencies of these links, were multiplied by the actual length of each, the products totaled, and the result was called the "Yale Traffic Index." It was found that more than 91 percent of the traffic on the unit could be accounted for by only fourteen "links" involving only seven of the sixteen areas. This was one of the first attempts to develop an evaluation scheme based on functional efficiency, although it should be noted that no stochastic aspects were considered and, as a result, no confidence measures were placed on the index. Furthermore, a more realistic and useful index would have incorporated the labor cost of the various types of personnel and would have attempted to relate the frequencies to such variables as the size of the unit staff and to the patient census.

The results of the study by Pelletier and Thompson were used in 1964 by an architect (17). In an article in which he discussed the lack of measures for nursing unit design, McLaughlin used an adaptation of the Yale Traffic Index and evaluated eight alternative shapes of nursing units having similar facilities. He also calculated the construction costs of each of the units. He did not, however, convert the Yale Index to a cost index nor did he combine this index with the construction cost.

A major contribution to the body of knowledge relative to interdepartmental traffic is the work of Souder (18) reported in 1964. The objectives of his study were to determine the factors which influence or control planning and design and the experimentation with and development of criteria for hospital planning and design. The report describes the present practice of hospital planning and presents the views of several panels of planning practitioners on the important aspects of hospital planning. Notable among these is that both architects and hospital administrators consider traffic within the hospital a major factor in planning decisions, that they would value highly additional quantitative information and performance measures to aid in their decision making, and that personal experience and intuition are their major tools in the performance of their functions.

In developing a conceptual framework for hospital planning, Souder hypothesized that many important aspects of the performance of a hospital care system are functions of the arrangement of physical resources and of operational patterns. Thus, the performance can be affected by planning choices, and alternative planning choices can be evaluated in terms of their anticipated effects on the hospital system performance. He also hypothesized that increased access to background data on hospital operational patterns should result in improved effectiveness of the planning process, citing as example the use of traffic data from present hospitals. Another of his hypotheses is that the development and examination of a large number of architectural arrangements and operational patterns should improve the effectiveness of the planning process and the quality of the end product.

Based upon the above findings and hypotheses, observations of interdepartmental traffic were made at an older, long-established eastern hospital and at a newly organized, newly constructed western hospital. The departments observed were two inpatient units, the radiology department, the central supply room, and the pharmacy, in order to obtain the widest cross-section of key personnel categories in action. The data recorded for each trip were the time, the person making it, the origin or destination, the path used, the purpose of the trip, the item transported, the conveyance used for transport. In addition, the time to perform several tasks was measured and two scales were developed to weigh the trips by the importance of the person making them: one of skill value and one of wage value.

The results were presented as a series of descriptive statistics accompanied by explanations and interpretations. A number of correlations were made, in particular between visitor traffic and patient census, nursing personnel trips and patient census, attending physicians' trips and private patient census, trips for admission and discharge of patients and number of patients admitted and discharged, trips of paperwork delivered and patient load, trips for job purposes and patient load. The above mentioned correlations were obtained for the two nursing units studied. The trips were assumed to be Poisson distributed in nature, and probabilities of numbers of trips occurring in ten minute intervals were computed. The plots of the observed frequencies and the theoretical frequencies were compared graphically. It should be noted that no tests of significance were performed and the statistics were of unstated accuracy.

The study concluded with the development of the rationale for computer utilization in hospital planning and presented the methodology and results obtained by employing a digital computer equipped with an oscilloscope to scan background data and measure the effectiveness of plans against scales of performance values. This computer was programmed to draw on the body of observed data to elicit recorded patterns of task volumes, task performance coincidence and task demands on people.

Souder's study relies to a great degree on descriptive statistics to the neglect of the development of general quantitative descriptions for interdepartmental traffic, and in the one attempt to describe the traffic with a probability distribution, the unstated accuracy of the statistical techniques employed renders the results nearly worthless. The study described herein, although not as extensive as Souder's, develops probability measures and confidence intervals for interdepartmental traffic. The significance of the results of Souder's research lies in the fact that the traffic patterns of the two hospitals studied were remarkably alike even though the hospitals were of different design and were located at opposite ends of the country. This indicates the feasibility of translating the results of this study to other hospitals without too much difficulty.

An industrial engineering doctoral dissertation in 1964 dealt with problems relevant to the present study. Gue studied the time patterns of patient calls for service and of services initiated by the nurse, with the purpose of predicting the effects of nursing response to patient needs of changes in the size of the ward nursing staff. He showed that the two stochastic processes generated by a patient demanding service and being administered service may both be approximated by a Poisson process, and asserted that the number of patients needing direct care is a random variable that tends to follow a Poisson distribution (19).

In 1964 Gross (20) reported another study which is similar to the one by Thompson (12). As part of a project to determine the cost of information handling in hospitals, the nurses wore pedometers to obtain the order of magnitude of the amount of walking in a 35 bed single-corridor type of nursing unit. No stochastic aspects were considered in Gross' study.

The problem of people moving to and from functional centers was considered by Winn (21) in 1963. In the development of a method to incorporate departments with no direct material handling contact with other departments, as part of the solution to the facilities location problem, he mentioned the need for making allowances for the number of people that move between departments. He indicated that a method could be developed to equate the movement of a person with the movement of a certain amount of material. The problem was dismissed by indicating that it was formidable due to the need to account for variables such as the "value" (as manifested by the wage rate) of the employee. No stochastic aspects of the problem were considered.

The operations research literature abounds with contributions to the study of traffic models. Unfortunately, these models deal with vehicular traffic and are not directly applicable to this study. Some of the solution techniques of these models have been linear programming (22), fluid dynamics (23), and the theory of differential equations (24). The applicability of these models to this study is extremely limited, if not nil.

Turning to the theory of stochastic processes as applied to hospital phenomena, it is found that the majority of the studies have dealt with the prediction of the census level. Notable among these are the works of Blumberg (25), Weckworth (26), Singer (27), Balintfy (28), Middlehoven (29), and Hsieh (30). Each of these studies shows the correlation of demand for staffing and supplies with the fluctuating care needs of hospital patients.

In summary, it can be seen that there is a dearth of studies dealing with traffic of people between locations, particularly if a stochastic description is desired, and that this description is of paramount importance in the development of quantitative measures for evaluating hospital layouts. Typical of the current literature is an article by Smith and Briggs (31) in which recommendations are given for the location of facilities, such recommendations not being based on sound, quantitative criteria. It is hoped this study will promote the development of quantitative criteria upon which decisions concerning location of facilities may be based.

CHAPTER III

METHOD OF PROCEDURE

The procedure employed in this study consisted of the following major steps.

1. Selection of a suitable hospital in which detailed frequencies of travel between the nursing unit and important functional centers would be observed and recorded.

2. Collection of detailed traffic data and concurrent information on patient census and nursing unit staff size.

3. Identification of important functional centers as indicated by the extent of their contribution to interdepartmental travel.

4. Identification of important categories of personnel as indicated by the extent to which they contribute to interdepartmental travel.

5. Identification of the effects of other factors, such as type of patient in the unit, different days, and direction of travel, on the travel frequencies.

6. Investigation of the feasibility of predicting travel frequencies by use of the patient census categorized by degree of illness.

7. Investigation of the feasibility of predicting travel frequencies by use of the size of the unit staff.

8. Development of a stochastic model to describe the travel frequencies of important categories of personnel identified in (4) above between the important functional centers identified in (3) above, due con-

sideration given to the results of (5) above.

These steps are discussed in turn under the separate headings to follow.

Selection of a Suitable Hospital

The hospital selected in the conduct of this study was South Fulton Hospital, in East Point, Georgia. South Fulton is a 152 bed short term, general, voluntary hospital located approximately eight miles south of downtown Atlanta, Georgia. Table 17, Appendix A, lists the facilities, services, and staffing of South Fulton Hospital in the same format used to list the facilities of the two hospitals in Souder's study (33). Figures 6, 7, 8, 9, and 10, Appendix A, show the floor plans and arrangement of South Fulton's facilities.

The main criterion used in selecting South Fulton was the relative ease with which the traffic information could be recorded. The hospital was built in 1963 and no additions have been built to alter the traffic patterns created by the original building. The layout results in a very simple traffic flow from floor to floor, and most of the interdepartmental traffic of interest in this study is accomplished by use of two elevators at central locations. Due to their non-central locations, the stairs are very seldom used. Thus, it was possible to record all the necessary information without having to station observers throughout the hospital.

Two nursing units were chosen for which detailed traffic data were gathered: one was a 61 bed surgical unit, and the other consisted of 44 medical beds and 15 pediatric beds.

Data Collection

To collect the data on which the study was based, an observer was stationed in front of the elevators on the nursing units. The exact locations are marked with an "X" on the respective floor plans. As explained previously, this location insured that virtually everybody entering or departing the unit was accounted for. The small percentage of employees using the stairs was requested to report to the observer as they entered and departed. Each employee entering or leaving the unit was questioned as to his origin or destination, and personnel classification if not obvious. Cooperation from the employees was excellent, and, after the first day of data collection, they volunteered the information without being questioned. A form was designed to record this information (see Figure 11, Appendix A, for sample data sheet), and separate forms were utilized for incoming and outgoing trips. A separate form was used each hour.

The data were collected during the six-week period from August 7, 1966, to September 17, 1966. The actual dates and nursing units observed are listed in Table 18, Appendix A. Detailed traffic frequencies were recorded from 7:00 a.m. until 3:00 p.m., the time of the regular day shift. At the end of the shift, the head nurse in the unit was interviewed and the patients were classified according to their degree of illness in three categories: total care patients, partial care patients, and self-care patients. This classification, developed by Connor (33), has been found useful by several researchers (19), (34), and (35), in predicting the demand for nursing services and was used in step (6) of this procedure. In addition to this information, the size of the unit staff for that day, i.e., the number of registered nurses, practical nurses, nurse's aides, orderlies, and ward clerks working in the unit, was obtained from the head nurse.

Identification of Important Functional Centers

To identify the important functional centers as indicated by the extent of their contribution to interdepartmental travel, a simple program was written for the Burroughs B-5500 computer to add the trips for each functional center and to compute the percentage contribution of each center to the total number of trips observed. This procedure was followed twice: once taking into consideration trips by doctors and volunteers, and again disregarding these classifications; the percentage contributions were then ranked in a manner similar to the ABC inventory classification scheme as described in (36) and (37). This ranking resulted in the selection of 45 percent of the centers for further study. These centers account for 75 percent of all trips observed.

Identification of Important Personnel Categories

To identify the important personnel classes as indicated by the extent of their contribution to interdepartmental travel, another simple computer program was written, this time to add the trips for each personnel class and to compute the percentage contribution of each personnel class to the total number of trips observed. This resulted in the elimination of one personnel category out of eleven originally identified, due to its small contribution to the total number of trips. In addition, the five categories of nursing personnel originally identified were combined into two categories: professional and non-professional nursing. Finally, it was decided to eliminate the categories of medical doctor and volunteer from further study since they are not salaried employees and would not affect measures of effectiveness in terms of direct cost to the institu-

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b_1 = regression coefficient associated with X_1

X_2 = number of patients in partial care category

b_2 = regression coefficient associated with X_2

X_3 = number of patients in self-care category

b_3 = regression coefficient associated with X_3

The regression equations were developed for trips into and out of the nursing units from and to the departments selected in step (3) by the employees identified in (4). These equations were developed using a standard multiple regression and correlation analysis computer program (38), and their "goodness" as predictors of traffic frequencies was ascertained by testing the coefficient of multiple regression using analysis of variance techniques.

Prediction of Travel Frequencies by Use of the Nursing Unit Staff

In order to investigate the feasibility of predicting the number of trips during the day shift by professional and non-professional nursing personnel using the number of these people assigned to the unit, the following linear model was tested

$$N = k + a_1 Y_1 + a_2 Y_2$$

in which

N = number of trips during the day shift

k = constant term

Y_1 = number of professional nursing persons assigned to the unit

a_1 = regression coefficient associated with Y_1

Y_2 = number of non-professional nursing persons assigned to the unit

a_2 = regression coefficient associated with Y_2

The regression equations were developed for trips into and out of the units from and to the departments selected in step (3) by professional and non-professional nursing employees. These equations were developed using a standard multiple regression and correlation analysis computer program, and their "goodness" as predictors of traffic frequencies was ascertained by testing the coefficient of multiple regression using analysis of variance techniques.

Development of Stochastic Model

The final step in the study was the development of a stochastic model to describe the traffic between the units and the important departments. Since a number of hospital phenomena have been adequately described by random processes (19), (25), (39), and (40), the Poisson distribution was chosen as a likely descriptor of hospital interdepartmental traffic. The mean number of trips per hour was computed for all the various cases to be considered according to the results of steps (3), (4), and (5), and the actual frequency distributions were compared with the Poisson distribution with the same mean. This analysis was done using a Chi-Square goodness of fit test.

CHAPTER IV

RESULTS

Identification of Important Functional Centers

Twenty-two trip origins and destinations were identified at the outset of the study. These are listed on the left-hand column of Table 1. This table lists the total number of trips observed between each nursing unit and the 22 locations identified, categorized as to incoming or outgoing trips. The total number of trips observed between both units and the 22 locations, and the percent contribution of each location is shown in the last two columns of Table 1. The percent contribution of each location, ranked in a manner similar to the ABC inventory classification, is presented in Figure 2. Table 2 is identical to Table 1 except that the trips by doctors and volunteers have been excluded. Figure 3 is the graphical presentation of Table 2 in a manner similar to Figure 2.

The effect of the volunteer personnel is evident in the fact that the location "lobby and admissions" changed from second in importance to fourteenth when the trips of volunteers were eliminated. This is explained by the fact that the volunteers at South Fulton return to the information desk in the lobby after completion of each assignment. To avoid introducing extraneous influences such as the one just explained, and since they are not salaried employees, volunteers were excluded from further analysis. Also, since doctors are not salaried employees and thus would not affect measures of effectiveness in terms of direct cost to the insti-

Table 1. Trips and Percent Contributions by Departments (Doctors and Volunteers Included)

Department	Surgical				Medical				Combined	
	Incoming Trips*		Outgoing Trips*		Incoming Trips*		Outgoing Trips*			
	Total	%	Total	%	Total	%	Total	%	Totals	%
Radiology	143	8.28	144	9.06	124	7.54	103	6.77	514	7.93
Surgery	166	9.61	140	8.81	164	9.97	138	9.07	608	9.38
Pharmacy	32	1.85	40	2.52	46	2.80	51	3.35	169	2.61
Dietary	172	9.96	159	10.00	174	10.58	162	10.65	667	10.29
Laboratory	86	4.98	80	5.03	97	5.90	88	5.79	351	5.41
Emergency	64	3.71	63	3.96	36	2.19	31	2.04	194	2.99
Housekeeping	76	4.40	59	3.71	112	6.81	59	3.88	306	4.72
Maintenance	11	0.64	12	0.75	20	1.22	19	1.25	62	0.96
Central Supply	135	7.82	128	8.05	112	6.81	97	6.38	472	7.28
Snack Bar	49	2.84	56	3.52	54	3.28	38	2.50	197	3.04
Cafeteria	97	5.62	85	5.35	109	6.63	111	7.30	402	6.20
Medical Records	5	0.29	4	0.25	5	0.30	2	0.13	16	0.25
Laundry	26	1.51	23	1.45	63	3.83	56	3.68	168	2.59
Lobby & Admissions	213	12.33	199	12.52	185	11.25	185	12.16	782	12.06
Business Office	20	1.16	16	1.01	16	0.97	18	1.18	70	1.08
Nursing Service	21	1.22	12	0.75	23	1.40	18	1.18	74	1.14
Isotopes Lab	11	0.64	5	0.31	7	0.43	8	0.53	31	0.48
EKG	22	1.27	12	0.75	32	1.95	24	1.58	90	1.39
Obstetrics	46	2.66	95	5.97	28	1.70	34	2.24	203	3.13
Other Nursing Unit**	317	18.36	246	15.47	219	13.31	255	16.77	1037	15.99
Classroom	7	0.41	6	0.38	12	0.73	18	1.18	43	0.66
Purchasing	8	0.46	6	0.38	7	0.43	6	0.39	27	0.42
Totals	1727	100.00	1590	100.00	1645	100.00	1521	100.00	6483	100.00

*Incoming and outgoing trips are from the viewpoint of the nursing unit.

**This item refers to traffic between the surgical and medical units.

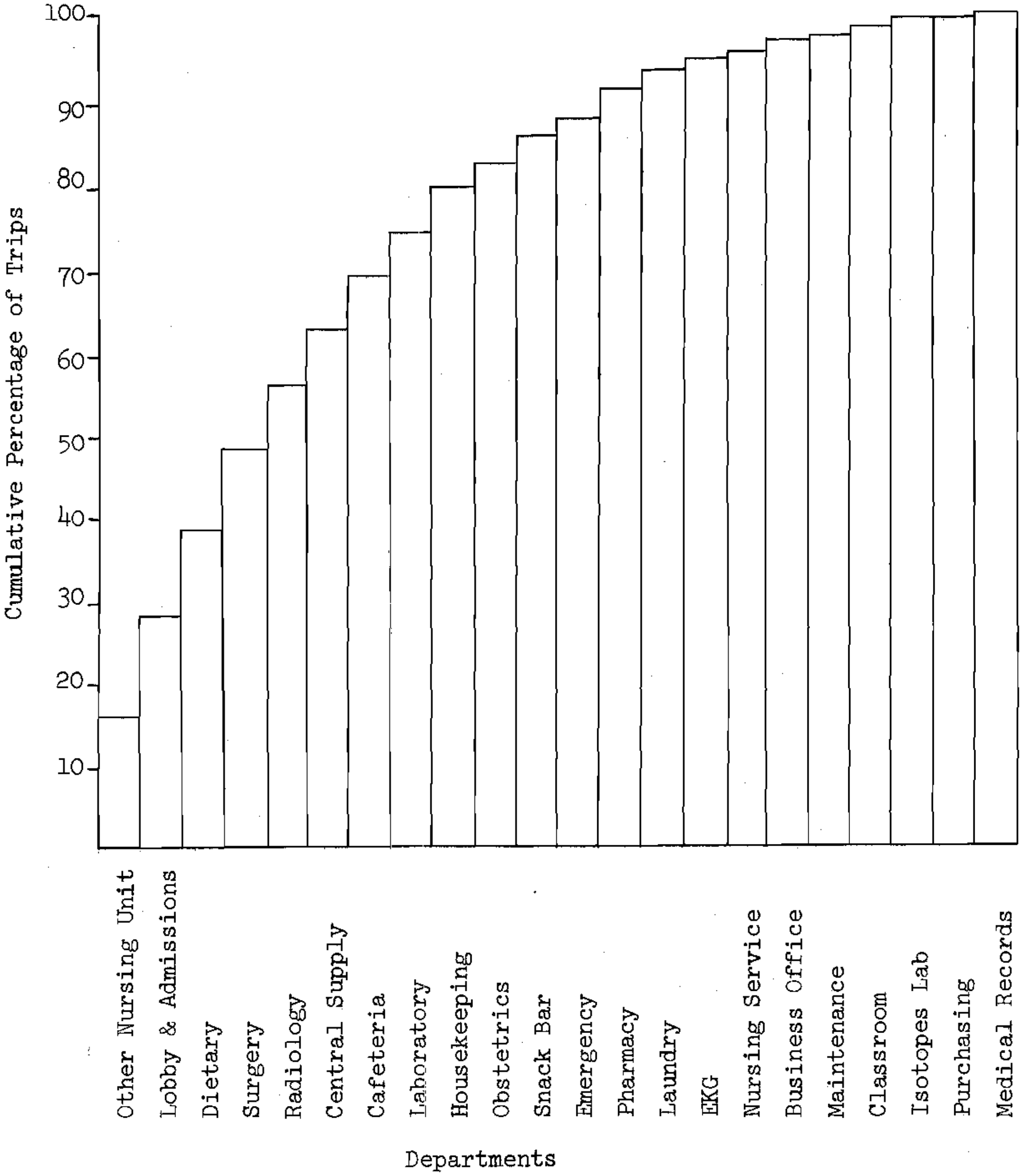


Figure 2. Ranking of Departments by Adaptation of ABC Inventory Classification (Doctors and Volunteers Included)

Table 2. Trips and Percent Contributions by Departments (Doctors and Volunteers Excluded)

Department	Surgical				Medical				Combined	
	Incoming Trips*		Outgoing Trips*		Incoming Trips*		Outgoing Trips*			
	Total	%	Total	%	Total	%	Total	%	Totals	%
Radiology	113	9.54	108	9.74	82	6.79	72	6.42	375	8.11
Surgery	120	10.14	111	10.01	121	10.02	118	10.53	470	10.17
Pharmacy	29	2.45	35	3.16	43	3.56	43	3.84	150	3.24
Dietary	155	13.09	140	12.62	155	12.83	149	13.29	599	12.96
Laboratory	67	5.66	60	5.41	79	6.54	73	6.51	279	6.04
Emergency	37	3.13	40	3.61	28	2.32	25	2.23	130	2.81
Housekeeping	75	6.33	59	5.32	109	9.02	59	5.26	302	6.53
Maintenance	8	0.68	8	0.72	16	1.32	14	1.25	46	1.00
Central Supply	119	10.05	112	10.10	89	7.37	77	6.87	397	8.59
Snack Bar	44	3.72	47	4.24	41	3.39	34	3.03	166	3.59
Cafeteria	92	7.77	81	7.30	102	8.44	107	9.55	382	8.26
Medical Records	3	0.25	2	0.18	5	0.41	1	0.09	11	0.24
Laundry	25	2.11	18	1.62	60	4.97	49	4.37	152	3.29
Lobby & Admissions	25	2.11	23	2.07	26	2.15	29	2.59	103	2.23
Business Office	16	1.35	15	1.35	16	1.32	17	1.52	64	1.38
Nursing Service	16	1.35	12	1.08	23	1.90	18	1.61	69	1.49
Isotopes Lab	5	0.42	3	0.27	6	0.50	7	0.62	21	0.46
EKG	16	1.35	10	0.90	25	2.07	21	1.87	72	1.56
Obstetrics	28	2.36	55	4.96	24	1.99	26	2.32	133	2.88
Other Nursing Unit**	176	14.86	158	14.25	139	11.51	159	14.18	632	13.68
Classroom	7	0.59	6	0.54	12	0.99	18	1.61	43	0.93
Purchasing	8	0.68	6	0.54	7	0.58	5	0.45	26	0.56
Totals	1184	100.00	1109	100.00	1208	100.00	1121	100.00	4622	100.00

*Incoming and outgoing trips are from the viewpoint of the nursing unit.

**This item refers to traffic between the surgical and medical units.

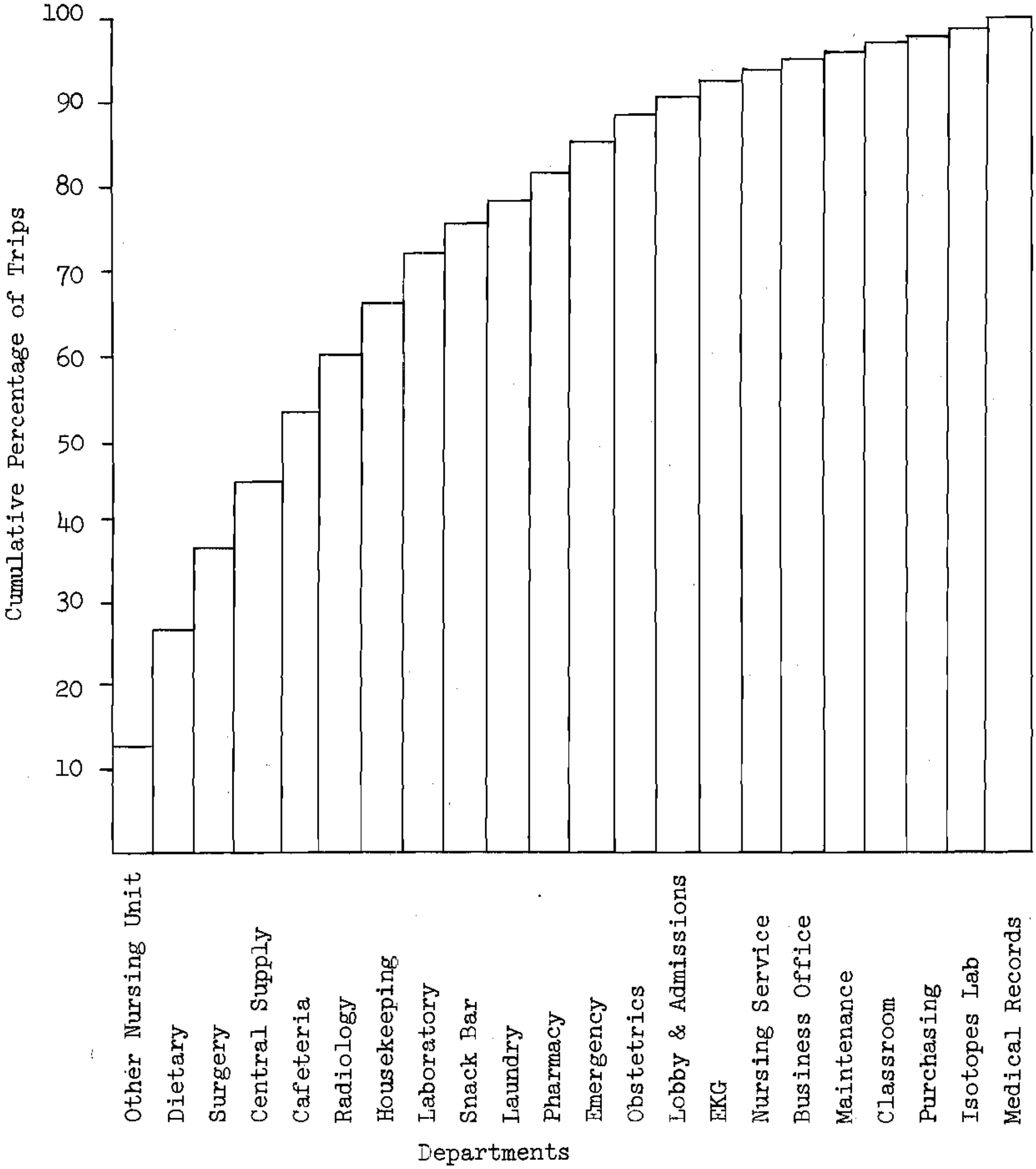


Figure 3. Ranking of Departments by Adaptation of ABC Inventory Classification (Doctors and Volunteers Excluded)

tution, they were excluded from further analysis.

Figure 3 indicates that there is a small group of departments accounting for a great number of trips. For instance, 50 percent of the departments identified account for 81 percent of the trips. In an effort to reduce the number of departments studied to a manageable size, the cafeteria and the snack bar were excluded from further study since the employees frequent these locations on their own time, and thus they would not affect measures of effectiveness in terms of direct cost to the institution. After this preliminary reduction, it can be seen that only 10 departments account for 75 percent of the total traffic. These were the first 10 departments encountered from left to right on the abscisa of Figure 3 after the exclusion of the cafeteria and snack bar. They were the following: surgical and medical units (for inter unit traffic), dietary, surgery, central supply, radiology, housekeeping, laboratory, laundry, pharmacy, and emergency.

Identification of Important Personnel Categories

Eleven personnel categories were identified at the outset of the study. These are listed in the left-hand column of Table 3. This table lists the total number of trips observed by each of the personnel classifications identified, categorized as to incoming or outgoing trips, and as to the unit in which they were observed. The total number of trips by each personnel category and the percentage contribution of each category are shown in the last two columns of Table 3. The percentage contribution of each category, ranked in a manner similar to the ABC inventory classification, is presented in Figure 4.

Table 3. Trips and Percent Contributions by Personnel Classifications

Personnel Classification	Surgical				Medical				Combined	
	Incoming Trips*		Outgoing Trips*		Incoming Trips*		Outgoing Trips*			
	Total	%	Total	%	Total	%	Total	%	Totals	%
Registered Nurse	144	8.34	134	8.43	148	9.00	144	9.47	570	8.79
Licensed Practical Nurse	23	1.33	20	1.26	30	1.82	32	2.10	105	1.62
Nursing Aide	286	16.56	290	18.24	296	17.99	302	19.86	1174	18.11
Orderly	189	10.94	175	11.01	132	8.02	109	7.17	605	9.33
Ward Clerk	29	1.68	25	1.57	39	2.37	38	2.50	131	2.02
Doctor	166	9.61	124	7.80	115	6.99	92	6.05	497	7.67
Housekeeping	170	9.84	124	7.80	170	10.33	131	8.61	595	9.17
Maintenance	12	0.69	8	0.50	19	1.16	18	1.18	57	0.89
Dietary	126	7.30	128	8.05	138	8.39	137	9.01	529	8.16
Technician	205	11.87	205	12.89	236	14.35	210	13.81	856	13.20
Volunteer	377	21.83	357	22.45	322	19.57	308	20.25	1364	21.04
Totals	1727	100.00	1590	100.00	1645	100.00	1521	100.00	6483	100.00

*Incoming and outgoing trips are from the viewpoint of the nursing unit.

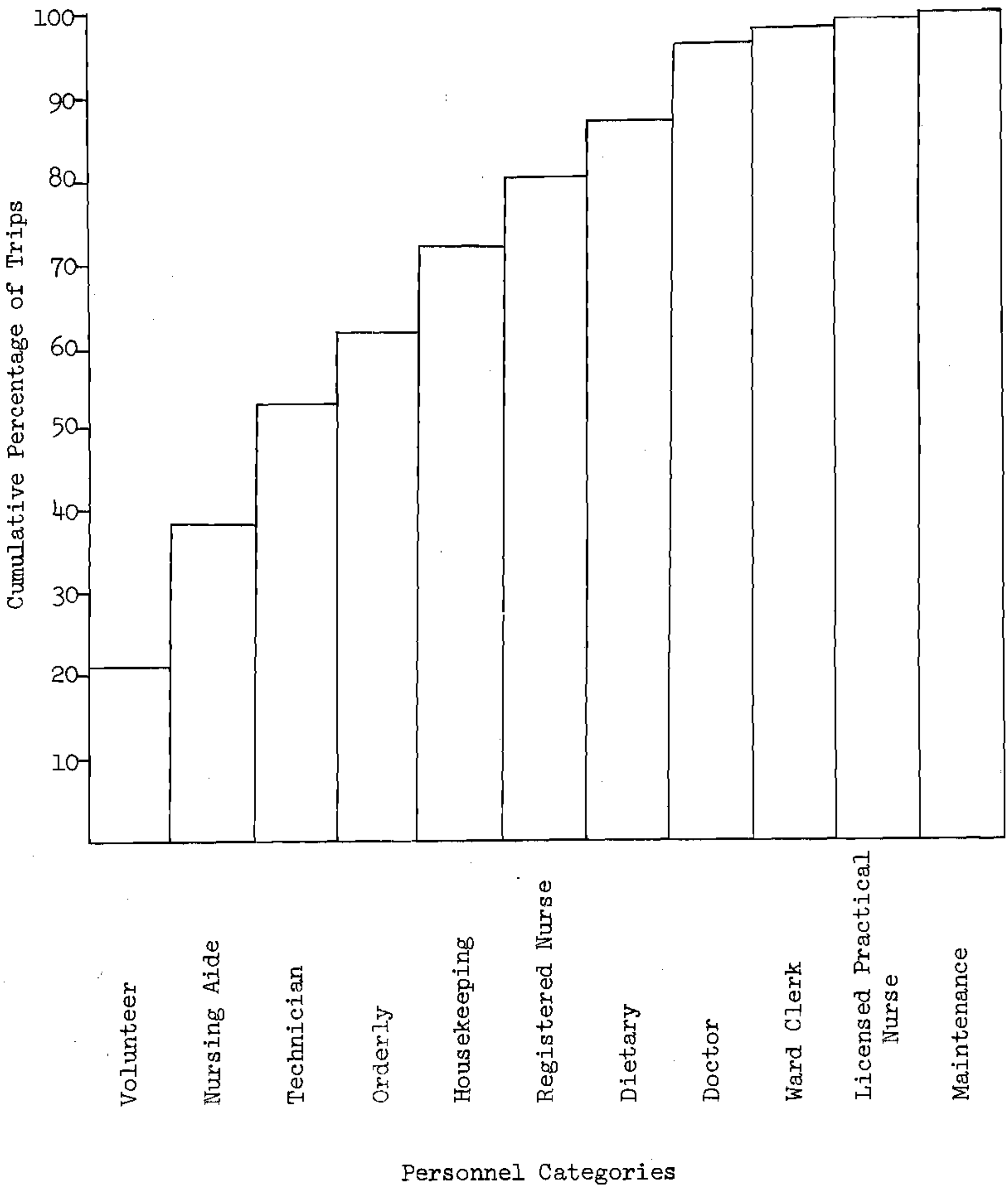


Figure 4. Ranking of Personnel Categories by Adaptation of ABC Inventory Classification

This analysis indicates that volunteers are the persons who do most of the interdepartmental travel, followed closely by the nursing aides. Technicians are the third class in order of importance, and orderlies the fourth. At this point in the analysis, it was decided to combine the categories of licensed practical nurse, nursing aide, orderly, and ward clerk into one category termed "non-professional nursing". This decision was based on the fact that the distinction between nursing aides and orderlies is merely one of sex, and the licensed practical nurses and ward clerks account for such a small percentage of traffic that no serious error in terms of monetary measures is induced if these two categories are combined with the aides.

It was also decided to eliminate maintenance personnel from further study due to the small contribution (0.89 percent) to traffic. In addition, volunteers and doctors were eliminated for reasons explained earlier. This resulted in the consideration of five personnel categories for further study: professional nursing, non-professional nursing, housekeeping, dietary, and technician personnel.

Identification of Other Significant Factors

The results of the analysis of variance are presented in Table 5. The response variable in this analysis is number of trips. The factors considered, along with pertinent information about them, are listed in Table 4.

The results of this analysis of variance are discussed in detail below, in terms of the main effects and the first order interactions.

Table 4. Factors Considered in Analysis of Variance

Factor	Identifying Code	Number of Levels	Type of Factor
Nursing Unit	I	2	Fixed, Crossed
Direction	J	2	Fixed, Crossed
Days	K(I)	7	Random, Nested
Departments	L	10	Fixed, Crossed
Personnel	M	5	Fixed, Crossed

Table 5. Analysis of Variance

Factor	Components of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	α Level of Significance
I	$\sigma^2_\epsilon + 100\ \sigma^2_{K(I)} + 700\ \sigma^2_{I}$	0.779	1	0.779	0.004	Not Significant
J	$\sigma^2_\epsilon + 50\ \sigma^2_{JK(I)} + 700\ \sigma^2_{J}$	15.018	1	15.018	18.450	0.01
IJ	$\sigma^2_\epsilon + 50\ \sigma^2_{JK(I)} + 350\ \sigma^2_{IJ}$	0.161	1	0.161	0.198	Not Significant
K(I)	$\sigma^2_\epsilon + 100\ \sigma^2_{K(I)}$	258.794	12	21.566	23.624	0.01
JK(I)	$\sigma^2_\epsilon + 50\ \sigma^2_{JK(I)}$	9.771	12	0.814	0.892	Not Significant
L	$\sigma^2_\epsilon + 10\ \sigma^2_{LK(I)} + 140\ \sigma^2_{L}$	2,066.572	9	229.619	24.823	0.01
IL	$\sigma^2_\epsilon + 10\ \sigma^2_{LK(I)} + 70\ \sigma^2_{IL}$	122.372	9	13.597	1.470	0.10
JL	$\sigma^2_\epsilon + 5\ \sigma^2_{JLK(I)} + 70\ \sigma^2_{JL}$	28.618	9	3.180	3.728	0.01
IJL	$\sigma^2_\epsilon + 5\ \sigma^2_{JLK(I)} + 35\ \sigma^2_{IJL}$	18.561	9	2.062	2.417	0.05
LK(I)	$\sigma^2_\epsilon + 10\ \sigma^2_{LK(I)}$	998.806	108	9.248	10.131	0.01
JLK(I)	$\sigma^2_\epsilon + 5\ \sigma^2_{JLK(I)}$	92.171	108	0.853	0.935	Not Significant
M	$\sigma^2_\epsilon + 20\ \sigma^2_{MK(I)} + 280\ \sigma^2_{M}$	3,296.519	4	824.130	62.449	0.01
IM	$\sigma^2_\epsilon + 20\ \sigma^2_{MK(I)} + 140\ \sigma^2_{IM}$	17.433	4	4.358	0.330	Not Significant

Table 5. Analysis of Variance (Concluded)

Factor	Components of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	α Level of Significance
JM	$\sigma^2_\epsilon + 10\ \sigma^2_{MJK(I)} + 140\ \sigma^2_{JM}$	16.221	4	4.055	5.727	0.01
IJM	$\sigma^2_\epsilon + 10\ \sigma^2_{MJK(I)} + 70\ \sigma^2_{IJM}$	1.793	4	0.448	0.633	Not Significant
MK(I)	$\sigma^2_\epsilon + 20\ \sigma^2_{MK(I)}$	633.449	48	13.197	14.457	0.01
MJK(I)	$\sigma^2_\epsilon + 10\ \sigma^2_{MJK(I)}$	33.986	48	0.708	0.776	Not Significant
LM	$\sigma^2_\epsilon + 28\ \sigma^2_{LM}$	13,618.853	36	378.301	414.412	0.001
ILM	$\sigma^2_\epsilon + 14\ \sigma^2_{ILM}$	328.881	36	9.136	10.008	0.01
JLM	$\sigma^2_\epsilon + 14\ \sigma^2_{JLM}$	223.893	36	6.219	6.813	0.01
IJLM	$\sigma^2_\epsilon + 7\ \sigma^2_{IJLM}$	181.950	36	5.054	5.537	0.01
MLK(I)	$\sigma^2_\epsilon + 2\ \sigma^2_{MLK(I)}$	3,120.666	432	7.224	7.913	0.01
MJLK(I)	σ^2_ϵ	394.357	432	0.913		
Totals		25,479.622	1399			

Nursing Unit

This effect, with an F-ratio less than unity, was clearly not significant. Since each nursing unit was devoted to mainly surgical or mainly medical patients, this result would indicate that the type of patient on the unit has no significant effect on the trips between the unit and other departments.

Direction

This effect was significant at an α level of 0.01, indicating that the number of trips into the unit was significantly different from the number of trips out of the nursing unit. Intuitively, one would expect the incoming and outgoing trips to be equal in number. However, due to the fact that the observations were terminated at 3:00 p.m., it is felt that there was a great number of trips observed for which its counterpart in the opposite direction was not observed.

Days

This effect was significant at an α level of 0.01, indicating that the number of trips varied significantly from day to day. This effect was investigated further with a Duncan Multiple Range Test. This test revealed that the two Saturdays observed showed a significantly lower number of trips. Investigation of hospital operating policy revealed that certain departments, such as surgery, do not operate on Saturdays, while others, such as the laboratory and radiology, only operate one-half day. Since these factors would affect the number of trips, it was decided to eliminate the observations obtained on Saturdays from further study. This implies that any model developed herein is only applicable to the days Monday through Friday.

Departments

This effect was significant at an α level of 0.01. This result was not surprising, since the previous ranking by percentages had indicated there were great differences in the number of trips categorized by departments.

Personnel

This effect was significant at an α level of 0.01. This result was not surprising either, since previous analysis had indicated there were great differences in the number of trips categorized by personnel.

Nursing Unit-Direction Interaction

This interaction, with an F-ratio of less than unity, was clearly not significant, indicating that different nursing units, and therefore different types of patients, did not produce significantly different numbers of incoming or outgoing trips.

Days-Direction Interaction

This interaction, with an F-ratio of less than unity, was clearly not significant, indicating that the number of incoming or outgoing trips did not vary significantly from day to day.

Nursing Unit-Department Interaction

This interaction could not be adjudged significant at an α level of 0.05. This indicates that different nursing units, and hence different types of patients, do not significantly affect the number of trips to or from the same department. Intuitively, this interaction would be expected to be significant since, for example, the number of trips to and from surgery would be expected to be greater for surgical than for medical patients. The fact that no significant difference was observed between the two types of patients in this study reflects the policy of the hospital studied not to segregate too rigidly between the two types of patients, a policy which may be a result of the hospital's high occupancy rate of approximately 90 percent. Furthermore, the medical floor has a wing of pediatric patients who may undergo surgical procedures. It is felt that these factors explain the lack of a significant difference in the number of trips between each unit and the same department.

<u>Direction-Department Interaction</u>

This interaction was significant at an α level of 0.05. This indicates that the number of incoming trips is significantly different from the number of outgoing trips for the same department. This can be explained by the fact that a number of personnel do not make single-purpose trips, that is, an incoming trip is immediately followed by an outgoing trip or vice-versa, but rather, personnel make multiple-purpose trips, or "rounds," in which several departments are visited before coming back to the place of origin. For instance, a typical trip by a nursing aide to central supply might also include a visit to the laboratory and the pharmacy.

<u>Days-Department Interaction</u>

This interaction was significant at an α level of 0.01. This is attributable to the fact mentioned earlier that some departments are closed or do not operate the entire day on certain days.

<u>Nursing Unit-Personnel Interaction</u>

This interaction, with an F-ratio of less than unity, was clearly not significant. This indicates that different nursing units, and therefore different types of patients do not give rise to significantly different numbers of trips by the same personnel classification.

Direction-Personnel Interaction

This interaction was significant at an α level of 0.01, indicating that the differences between the number of incoming and outgoing trips vary from one personnel classification to another. This indicates that there are some employees more likely to travel "making rounds" than others.

Days-Personnel Interaction

This interaction was significant at an α level of 0.01. This indicates that certain classes of personnel are more likely to travel on certain days than on other days and is probably a result of the fact that, since some departments were closed during certain of the study days, the personnel assigned to these departments obviously did not travel those days.

Department-Personnel Interaction

This interaction was significant at an α level of 0.001. This indicates that all nursing unit-department traffic links are not travelled with the same frequency by all personnel classifications. For example, dietary personnel would not be expected to travel between the units and surgery, and likewise nursing personnel would not be expected to travel between the units and the housekeeping department. The department-personnel interaction is presented graphically in Figures 12 through 21 in Appendix B. This interaction indicates that it is not necessary to consider all categories of personnel when analyzing in depth each nursing unit-department pair.

The results of the analysis of variance can be summarized as follows: the number of trips between each unit and the other departments considered is approximately equal for each unit and remains constant from day to day, weekends excluded. The employees make rounds and thus the number of incoming trips is not equal to the number of outgoing trips for each department considered. Furthermore, there are certain departments which are not visited by all employees.

As a result of the highly significant interaction between personnel classification and departments, it was decided to limit the in depth study of each department to certain personnel classes only. These classes account for the majority of the trips to or from that department. The department-personnel combinations selected are listed in Table 6.

Prediction of Travel Frequencies by Three-way Patient Classification

Connor (33) showed that there was a linear relationship between the degree of illness of patients, as reflected by their degree of self-sufficiency, and the nursing care required. He formulated an index based on a patient classification system, to anticipate the total hours of direct care to be furnished to a patient population categorized as to the number of total, partial, or self-care patients. The index was as follows:

$$I = 2.5\ X_1 + 1.0\ X_2 + 0.5\ X_3$$

in which

X_1 = number of patients in total care category

X_2 = number of patients in partial care category

X_3 = number of patients in self-care category

Since each trip between a department and a nursing unit presumably has the ultimate objective of satisfying a patient need, the relationship

Table 6. Department-Personnel Combinations Studied

Department	Personnel Selected
Radiology	Non-professional Nursing
Surgery	Professional Nursing, Non-professional Nursing
Pharmacy	Non-professional Nursing, Technician
Dietary	Non-professional Nursing, Dietary
Laboratory	Non-professional Nursing, Technician
Emergency	Professional Nursing, Non-professional Nursing, Technician
Housekeeping	Housekeeping
Central Supply	Non-professional Nursing, Technician
Laundry	Non-professional Nursing
Other Nursing Unit	Professional Nursing, Non-professional Nursing, Housekeeping, Dietary, Technician

between the number of trips observed for each department-personnel combination listed in Table 6, and the three-way patient classification mentioned above, was investigated by means of multiple regression. Specifically, the following linear model was tested:

$$N = c + b_1 X_1 + b_2 X_2 + b_3 X_3$$

in which X_1, X_2, and X_3 are defined as before, N is the number of trips during the day shift into or out of the nursing unit, b_1, b_2, and b_3 are the coefficients associated with X_1, X_2, and X_3, and c is a constant term.

Tables 7, 8, 9, and 10 present the summaries of the multiple regression analyses for each nursing unit for incoming and outgoing trips. Each table presents the department under study, the personnel classification making the trips, the constant term, the regression coefficients, the coefficient of multiple correlation, the standard error of estimate, and the F-ratio from the analysis of variance for the multiple linear regression. This F-ratio was used to ascertain the significance of the correlation coefficient.

The multiple correlation coefficients ranged from 0.25 to 0.99, indicating that the three-way patient classification is not a uniformly good predictor of travel frequencies. Furthermore, the same department-personnel combination exhibits a different correlation depending on the nursing unit involved or on the direction of the trip. For instance, the trips from pharmacy to the surgical unit by non-professional nursing personnel show a correlation coefficient of 0.83 with the three-way patient classification. If the direction is reversed so that the trips are

Table 7. Multiple Regression Analyses for Incoming Trips Using the Three-way Patient Classification as Predictor, Surgical Unit

Origin	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Radiology	Non-professional Nursing	-68.207	0.583	1.853	1.194	0.82	5.241	1.334
Surgery	Professional Nursing	-75.475	0.467	2.475	0.067	0.92	2.838	3.858
Surgery	Non-professional Nursing	5.943	-0.728	1.033	-0.805	0.54	9.610	0.269
Pharmacy	Non-professional Nursing	- 7.235	-0.165	0.334	0.006	0.83	1.115	1.480
Pharmacy	Technician	14.473	0.012	-0.498	0.094	0.92	0.629	3.831
Dietary	Non-professional Nursing	-20.613	-0.595	-0.990	0.203	0.79	4.703	1.124
Dietary	Dietary	28.411	-0.592	0.095	0.451	0.95	1.120	6.644
Laboratory	Non-professional Nursing	-19.655	0.296	0.416	0.308	0.75	1.708	0.857
Laboratory	Technician	2.095	-0.030	0.027	0.271	0.81	1.276	1.243
Emergency	Professional Nursing	-14.694	0.085	0.350	0.248	0.83	1.019	1.528
Emergency	Non-professional Nursing	-43.149	0.157	1.120	0.646	0.93	1.752	4.472
Emergency	Technician	-13.099	0.142	0.261	0.243	0.69	1.378	0.621
Housekeeping	Housekeeping	-11.909	-0.021	0.805	-0.104	0.34	6.467	0.089
Central Supply	Non-professional Nursing	-30.263	0.210	1.046	0.367	0.43	6.826	0.149
Central Supply	Technician	15.164	-0.049	-0.064	-0.464	0.68	2.816	0.573
Laundry	Non-professional Nursing	6.405	-0.123	0.131	-0.325	0.93	0.662	4.533
Medical Unit	Professional Nursing	- 0.145	-0.060	0.084	0.046	0.36	1.809	0.097

Table 7. Multiple Regression Analyses for Incoming Trips Using the Three-way Patient Classification as Predictor, Surgical Unit (Concluded)

Origin	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Medical Unit	Non-professional Nursing	25.785	0.423	-0.725	-0.163	0.97	1.114	10.612
Medical Unit	Housekeeping	14.053	-0.391	-0.728	0.564	0.94	1.479	4.719
Medical Unit	Dietary	- 0.767	0.005	-0.005	0.124	0.44	1.463	0.164
Medical Unit	Technician	5.222	0.091	0.336	-0.463	0.75	2.847	0.848

Table 8. Multiple Regression Analyses for Outgoing Trips Using the Three-way Patient Classification as Predictor, Surgical Unit

Destination	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Radiology	Non-professional Nursing	-54.421	0.584	1.422	1.088	0.64	7.470	0.473
Surgery	Professional Nursing	-40.588	0.132	1.532	-0.192	0.74	4.005	0.820
Surgery	Non-professional Nursing	- 7.406	-0.048	0.925	-0.291	0.25	11.838	0.045
Pharmacy	Non-professional Nursing	- 5.664	-0.079	0.262	0.022	0.56	1.587	0.304
Pharmacy	Technician	7.176	-0.038	-0.215	0.059	0.92	0.317	3.731
Dietary	Non-professional Nursing	-14.719	-0.703	0.931	0.067	0.77	5.174	0.969
Dietary	Dietary	34.929	-0.437	-0.102	-0.736	0.95	1.272	5.682
Laboratory	Non-professional Nursing	- 4.262	0.159	0.093	0.102	0.47	2.642	0.195
Laboratory	Technician	1.372	-0.252	0.284	-0.066	0.57	2.772	0.324
Emergency	Professional Nursing	-10.727	0.001	0.374	0.018	0.57	1.510	0.332
Emergency	Non-professional Nursing	-34.577	0.151	0.939	0.482	0.72	3.344	0.729
Emergency	Technician	-15.491	0.222	0.312	0.231	0.75	1.281	0.857
Housekeeping	Housekeeping	27.479	-0.131	-0.018	-1.025	0.82	3.916	1.405
Central Supply	Non-professional Nursing	9.422	0.441	-0.620	0.327	0.94	1.229	5.363
Central Supply	Technician	-25.927	0.023	1.083	-0.094	0.95	0.970	6.645
Laundry	Non-professional Nursing	10.835	-0.285	0.101	-0.457	0.77	1.977	0.997
Medical Unit	Professional Nursing	15.417	-0.483	-0.169	-0.122	0.88	1.560	2.257

Table 8. Multiple Regression Analyses for Outgoing Trips Using the Three-way Patient Classification as Predictor, Surgical Unit (Concluded)

Destination	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Medical Unit	Non-professional Nursing	9.614	0.327	-0.234	0.008	0.88	1.298	2.401
Medical Unit	Housekeeping	10.860	-0.112	-0.327	0.108	0.87	0.819	1.982
Medical Unit	Dietary	- 5.776	0.049	0.069	0.385	0.99	0.285	37.720*
Medical Unit	Technician	- 0.878	0.230	-0.008	0.422	0.55	3.229	0.293

*F-ratio significant at $\alpha = 0.05$.

Table 9. Multiple Regression Analyses for Incoming Trips Using the Three-way Patient Classification as Predictor, Medical Unit

Origin	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Radiology	Non-professional Nursing	68.758	-1.338	-0.821	-0.588	0.74	7.242	0.816
Surgery	Professional Nursing	23.111	-0.314	-0.224	-0.566	0.98	0.540	16.330
Surgery	Non-professional Nursing	43.279	-0.743	-0.165	-0.609	0.53	5.799	0.258
Pharmacy	Non-professional Nursing	19.331	-0.358	-0.267	-0.344	0.86	0.612	1.857
Pharmacy	Technician	14.157	-0.229	-0.161	-0.253	0.96	0.164	9.634
Dietary	Non-professional Nursing	25.228	-0.544	-0.133	-0.401	0.94	0.907	4.805
Dietary	Dietary	0.029	0.303	0.289	0.196	0.67	2.360	0.530
Laboratory	Non-professional Nursing	44.919	-0.824	-0.553	-0.855	0.87	1.224	2.003
Laboratory	Technician	54.934	-0.803	-0.749	-0.950	0.49	5.100	0.216
Emergency	Professional Nursing	4.632	-0.084	-0.020	-0.086	0.25	1.786	0.047
Emergency	Non-professional Nursing	40.023	-0.784	-0.512	-0.707	0.88	1.121	2.340
Emergency	Technician	7.865	-0.212	-0.032	-0.073	0.68	1.358	0.569
Housekeeping	Housekeeping	-36.523	1.045	0.433	1.528	0.97	1.881	1.170
Central Supply	Non-professional Nursing	23.014	-0.087	-0.454	-0.380	0.91	1.626	3.283
Central Supply	Technician	-33.397	0.746	0.515	0.757	0.80	1.419	1.209
Laundry	Non-professional Nursing	22.370	-0.225	-0.221	-0.492	0.63	2.968	0.450
Surgical Unit	Professional Nursing	25.825	-0.433	-0.313	-0.463	0.62	1.451	0.415

Table 9. Multiple Regression Analyses for Incoming Trips Using the Three-way Patient Classification as Predictor, Medical Unit (Concluded)

Origin	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Surgical Unit	Non-professional Nursing	48.275	-1.096	-0.145	-1.006	0.94	2.377	5.468
Surgical Unit	Housekeeping	11.826	-0.178	-0.175	-0.084	0.73	1.484	0.745
Surgical Unit	Dietary	33.660	-0.495	-0.528	-0.648	0.87	1.251	2.172
Surgical Unit	Technician	-14.684	0.372	0.289	0.481	0.40	3.101	0.125

Table 10. Multiple Regression Analyses for Outgoing Trips Using the Three-way Patient Classification as Predictor, Medical Unit

Destination	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Radiology	Non-professional Nursing	73.658	-1.428	-0.899	-0.811	0.64	8.455	0.456
Surgery	Professional Nursing	35.131	-0.535	-0.410	-0.852	0.83	2.224	1.457
Surgery	Non-professional Nursing	2.276	0.093	0.365	0.185	0.42	6.575	0.146
Pharmacy	Non-professional Nursing	9.093	0.193	-0.309	-0.270	0.90	2.000	2.999
Pharmacy	Technician	- 8.370	0.181	0.104	0.223	0.63	0.924	0.439
Dietary	Non-professional Nursing	- 3.627	0.113	0.179	0.008	0.86	0.887	1.875
Dietary	Dietary	- 9.748	0.478	0.346	0.591	0.87	0.923	2.010
Laboratory	Non-professional Nursing	12.780	-0.184	-0.043	-0.326	0.69	2.370	0.599
Laboratory	Technician	-14.136	0.628	0.037	0.428	0.82	2.648	1.369
Emergency	Professional Nursing	-22.136	0.513	0.278	0.383	0.88	0.873	2.323
Emergency	Non-professional Nursing	37.436	-0.647	-0.547	0.707	0.93	0.782	4.421
Emergency	Technician	8.628	-0.245	-0.005	-0.121	0.66	1.751	0.511
Housekeeping	Housekeeping	- 7.805	0.223	0.166	0.644	0.99	0.300	138.652*
Central Supply	Non-professional Nursing	58.260	-0.706	-0.948	-1.158	0.91	2.268	3.146
Central Supply	Technician	7.504	0.010	-0.151	-0.083	0.55	2.163	0.295
Laundry	Non-professional Nursing	-11.742	0.242	0.381	0.278	0.61	3.248	0.387

Table 10. Multiple Regression Analyses for Outgoing Trips Using the Three-way Patient Classification as Predictor, Medical Unit (Concluded)

Destination	Personnel	c	b_1	b_2	b_3	r^2	Standard Error of Estimate	$F_{3,2}$
Surgical Unit	Professional Nursing	26.026	-0.508	-0.296	-0.395	0.53	2.497	0.260
Surgical Unit	Non-professional Nursing	7.544	-0.322	0.265	0.048	0.78	3.450	1.070
Surgical Unit	Housekeeping	36.660	-0.495	-0.528	-0.648	0.87	1.251	2.173
Surgical Unit	Dietary	18.232	-0.216	-0.246	-0.525	0.87	1.534	2.071
Surgical Unit	Technician	-14.324	0.177	0.459	0.767	0.75	4.219	0.857

*F-ratio significant at $\alpha = 0.05$

to the pharmacy from the surgical unit, the correlation coefficient is 0.56. If the trips are considered from pharmacy to the medical unit again by non-professional nursing, the correlation coefficient becomes 0.86, whereas if the direction is changed again, the correlation coefficient becomes 0.90. There is a predominance of low (less than 0.80) correlation coefficients. In addition, a correlation coefficient as high as 0.96 could not be adjudged significant even at an α level of 0.10 using the F-ratio from the analysis of variance as criterion. In fact, only two out of 84 coefficients showed an F-ratio significant at the 0.05 level. All these factors indicate that the three-way patient classification is not a very useful predictor of traffic frequencies between departments.

Prediction of Travel Frequencies by Use of the Nursing Unit Staff

The relationship between the size of the nursing staff and the trips by nursing personnel between the unit and the various departments considered was investigated by testing the model

$$N = k + a_1 Y_1 + a_2 Y_2$$

in which

N = number of trips during the day shift

k = constant term

Y_1 = number of professional nursing persons assigned to the unit

a_1 = regression coefficient associated with Y_1

Y_2 = number of non-professional nursing persons assigned to the unit

a_2 = regression coefficient associated with Y_2

Tables 11, 12, 13, and 14 present the summaries of the multiple regression analyses for each nursing unit for incoming and outgoing trips. Each table presents the department under study, the personnel classification making the trip, the constant term, the regression coefficients, the coefficient of multiple correlation, the standard error of estimate, and the F-ratio for the analysis of variance for the multiple linear regression. This F-ratio was used to ascertain the significance of the correlation coefficient.

The multiple correlation coefficients ranged from 0.00 to 0.97, indicating that the size of the unit staff is not a uniformly good predictor of traffic frequencies. Furthermore, just as in the investigation of the correlation of trips with the three-way patient classification, the same department-personnel combination exhibits a different correlation depending on the nursing unit involved or on the direction of the trip. For instance, the trips from emergency to the surgical unit by professional nursing show a correlation of 0.80. If the trips in the opposite direction (surgical unit to emergency) are considered, the correlation is 0.49. If trips from emergency into the medical unit are considered, the correlation becomes 0.08, and if again the trips in the opposite direction are considered, the correlation becomes 0.87. There is a predominance of low (less than 0.80) correlation coefficients. In addition, a coefficient as high as 0.88 could not be adjudged significant even at an α level of 0.10. In fact, only two out of 73 coefficients showed an F-ratio significant at the 0.05 level. All these factors indicate that the size of the unit staff is not a very good predictor of traffic frequencies.

Table 11. Multiple Regression Analyses for Incoming Trips Using the Size of the Unit Staff as a Predictor, Surgical Unit

Origin	Personnel	k	a_1	a_2	r^2	Standard Error of Estimate	$F_{2,3}$
Radiology	Professional Nursing	- 3.000	0.167	0.333	0.35	0.624	0.214
Radiology	Non-professional Nursing	61.000	-0.833	-5.167	0.44	6.650	0.442
Surgery	Professional Nursing	62.000	-1.167	-6.333	0.66	4.515	1.181
Surgery	Non-professional Nursing	26.000	-0.167	-1.333	0.09	85.722	0.013
Pharmacy	Professional Nursing	-12.000	-0.167	1.667	0.88	0.624	5.357
Pharmacy	Non-professional Nursing	1.000	0.000	0.000	0.00	1.633	0.000
Dietary	Professional Nursing	- 4.000	0.000	0.500	0.63	0.408	1.000
Dietary	Non-professional Nursing	-10.000	-1.500	2.500	0.42	5.715	0.319
Laboratory	Professional Nursing	- 6.000	0.333	0.667	0.71	0.471	1.500
Laboratory	Non-professional Nursing	5.000	0.667	0.667	0.45	1.886	0.375
Emergency	Professional Nursing	2.000	1.000	-0.500	0.80	0.913	2.600
Emergency	Non-professional Nursing	- 3.000	2.000	0.000	0.53	3.367	0.588
Housekeeping	Professional Nursing	*	--	--	--	--	--
Housekeeping	Non-professional Nursing	4.000	-1.000	0.000	0.79	0.816	2.500
Central Supply	Professional Nursing	14.000	0.000	-1.500	0.41	2.198	0.310
Central Supply	Non-professional Nursing	15.000	3.500	-2.000	0.70	4.416	1.423
Laundry	Professional Nursing	1.000	0.167	-0.167	0.44	0.471	0.375
Laundry	Non-professional Nursing	9.000	-1.333	-0.166	0.91	0.624	7.286
Medical Unit	Professional Nursing	10.000	-0.167	-0.833	0.33	1.491	0.188
Medical Unit	Non-professional Nursing	31.000	-0.833	-2.667	0.46	3.325	0.399

*No trips were observed by this personnel classification from this department throughout the study.

Table 12. Multiple Regression Analyses for Outgoing Trips Using the Size of the Unit Staff as a Predictor, Surgical Unit

Destination	Personnel	k	a_1	a_2	r^2	Standard Error of Estimate	$F_{2,3}$
Radiology	Professional Nursing	- 3.000	-0.167	0.333	0.35	0.624	0.214
Radiology	Non-professional Nursing	55.000	-1.833	-4.167	0.36	7.454	0.218
Surgery	Professional Nursing	41.000	-0.833	-4.167	0.54	4.110	0.617
Surgery	Non-professional Nursing	63.000	0.500	-6.000	0.42	9.065	0.322
Pharmacy	Professional Nursing	-16.000	0.167	2.167	0.95	0.471	15.375**
Pharmacy	Non-professional Nursing	10.000	0.833	-0.666	0.54	1.312	0.629
Dietary	Professional Nursing	- 4.000	0.000	0.500	0.63	0.408	1.000
Dietary	Non-professional Nursing	12.000	-2.000	3.000	0.50	5.715	0.510
Laboratory	Professional Nursing	- 7.000	0.167	0.833	0.75	0.471	1.875
Laboratory	Non-professional Nursing	- 1.999	0.833	0.167	0.56	1.247	0.696
Emergency	Professional Nursing	0.000	0.667	0.167	0.49	1.312	0.484
Emergency	Non-professional Nursing	- 7.000	2.833	0.167	0.75	2.625	1.900
Housekeeping	Professional Nursing	*	--	--	--	--	--
Housekeeping	Non-professional Nursing	10.000	-1.500	-0.500	0.88	0.816	5.125
Central Supply	Professional Nursing	20.000	0.333	-2.333	0.56	2.494	0.696
Central Supply	Non-professional Nursing	16.000	1.500	-1.500	0.53	3.367	0.596
Laundry	Professional Nursing	*	--	--	--	--	--
Laundry	Non-professional Nursing	-15.000	-0.167	2.167	0.59	2.055	0.809
Medical Unit	Professional Nursing	-19.000	0.667	2.333	0.56	2.211	0.682
Medical Unit	Non-professional Nursing	29.000	-0.500	-2.500	0.70	1.633	1.406

*No trips were observed by this personnel classification to this department throughout the study.

**F-ratio significant at $\alpha = 0.05$

Table 13. Multiple Regression Analyses for Incoming Trips Using the Size of the Unit Staff as a Predictor, Medical Unit

Origin	Personnel	k	a_1	a_2	r^2	Standard Error of Estimate	$F_{2,3}$
Radiology	Professional Nursing	- 8.286	0.786	0.571	0.44	0.598	0.367
Radiology	Non-professional Nursing	- 12.143	6.143	0.286	0.69	6.355	1.389
Surgery	Professional Nursing	- 23.571	1.571	2.143	0.66	1.662	1.185
Surgery	Non-professional Nursing	106.143	-7.643	-6.286	0.54	4.678	0.633
Pharmacy	Professional Nursing	- 7.714	1.214	0.429	0.79	0.598	2.467
Pharmacy	Non-professional Nursing	- 31.714	2.714	2.429	0.43	2.488	0.344
Dietary	Professional Nursing	4.000	-1.000	0.000	0.79	0.816	2.500
Dietary	Non-professional Nursing	9.714	-0.214	-0.429	0.18	2.087	0.049
Laboratory	Professional Nursing	- 3.143	0.143	0.286	0.24	1.024	0.091
Laboratory	Non-professional Nursing	- 12.429	1.929	0.857	0.52	1.711	0.549
Emergency	Professional Nursing	- 0.571	0.071	0.143	0.08	1.504	0.011
Emergency	Non-professional Nursing	5.286	0.714	0.571	0.77	1.234	2.219
Housekeeping	Professional Nursing	*	--	--	--	--	--
Housekeeping	Non-professional Nursing	*	--	--	--	--	--
Central Supply	Professional Nursing	66.857	-4.857	-4.714	0.97	0.617	23.219**
Central Supply	Non-professional Nursing	25.714	-1.214	-1.429	0.27	3.112	0.117
Laundry	Professional Nursing	- 1.571	0.071	0.143	0.24	0.512	0.091
Laundry	Non-professional Nursing	- 29.857	2.357	2.714	0.52	2.686	0.545
Surgical Unit	Professional Nursing	11.857	-0.357	-0.714	0.42	1.371	0.316
Surgical Unit	Non-professional Nursing	- 55.286	4.286	4.571	0.43	5.309	0.345

*No trips were observed by this personnel classification from this department throughout the study.

**F-ratio significant at $\alpha = 0.05$

Table 14. Multiple Regression Analyses for Outgoing Trips Using the Size of the Unit Staff as a Predictor, Medical Unit

Destination	Personnel	k	a_1	a_2	r^2	Standard Error of Estimate	$F_{2,3}$
Radiology	Professional Nursing	- 1.571	0.071	0.143	0.24	0.512	0.091
Radiology	Non-professional Nursing	7.000	4.000	-1.000	0.61	7.071	0.908
Surgery	Professional Nursing	-12.143	0.643	1.286	0.35	3.036	0.209
Surgery	Non-professional Nursing	0.015	-11.929	-8.857	0.76	3.864	2.028
Pharmacy	Professional Nursing	-14.429	1.929	0.857	0.90	0.512	6.136
Pharmacy	Non-professional Nursing	-47.857	3.857	3.714	0.50	3.324	0.491
Dietary	Professional Nursing	-11.000	0.500	1.000	0.51	1.472	0.538
Dietary	Non-professional Nursing	19.429	- 1.929	-0.857	0.73	0.964	1.731
Laboratory	Professional Nursing	- 9.857	0.857	0.714	0.32	1.024	0.170
Laboratory	Non-professional Nursing	-55.143	4.143	4.286	0.87	1.309	4.722
Emergency	Professional Nursing	23.143	- 2.643	-1.286	0.87	0.740	4.739
Emergency	Non-professional Nursing	-10.286	1.786	0.571	0.68	1.300	1.261
Housekeeping	Professional Nursing	*	--	--	--	--	--
Housekeeping	Non-professional Nursing	*	--	--	--	--	--
Central Supply	Professional Nursing	66.857	- 4.857	-4.714	0.92	1.024	8.443
Central Supply	Non-professional Nursing	10.714	0.286	-0.429	0.20	4.342	0.060
Laundry	Professional Nursing	- 1.571	0.071	0.143	0.24	0.512	0.091
Laundry	Non-professional Nursing	14.143	- 1.643	-0.286	0.41	3.036	0.309
Surgical Unit	Professional Nursing	- 9.286	1.786	0.571	0.50	2.087	0.489
Surgical Unit	Non-professional Nursing	26.714	- 1.714	-1.429	0.15	4.493	0.035

*No trips were observed by this personnel classification from this department throughout the study.

Development of the Stochastic Traffic Model

The final step of this study was the development of the stochastic model to describe the traffic between the units and the departments studied. From the analysis of variance, it will be remembered that the different nursing units did not significantly affect the number of trips, but there was a significant difference between the number of incoming and outgoing trips. Accordingly, the incoming trips for both nursing units were pooled, and the same was done with the outgoing trips. For trips between the two nursing units, all trips in one direction were pooled, giving rise to two classifications of trips: "into medical," denoting trips from the surgical to the medical unit, and "into surgical," denoting trips from the medical to the surgical unit, that is, inter unit travel in the opposite direction.

It was hypothesized that the Poisson distribution would be a good descriptor of interdepartmental traffic. Accordingly, the mean number of hourly trips was computed, frequency histograms were constructed, and the observed frequency distributions were compared with the Poisson distribution with the same mean. The comparison was done by means of a Chi-Square goodness of fit test. Appendix C presents the frequency histograms for the various cases considered, and Table 15 summarized the results of the Chi-Square tests. This table presents the department of origin or destination of the trips, the personnel classification traveling, the computed Chi-Square value, the degrees of freedom of the test, the α level at which the Chi-Square value would have indicated a significant deviation from the Poisson hypothesis, and the conclusion from the test based on a decision rule that would reject the Poisson hypothesis if the Chi-Square

Table 15. Summary Results of Goodness of Fit Tests for the Poisson Distribution

Origin or Destination	Personnel Classification	Chi-Square Value	d.f.	Level of Significance	Conclusion
Into Medical	Professional Nursing	0.391	1	0.700	Accept
Into Surgical	Professional Nursing	0.565	1	0.500	Accept
Into Medical	Non-professional Nursing	0.173	2	0.950	Accept
Into Surgical	Non-professional Nursing	0.481	2	0.800	Accept
Into Medical	Housekeeping	4.350	1	0.050	Reject
Into Surgical	Housekeeping	2.140	2	0.500	Accept
Into Medical	Dietary	0.843	1	0.500	Accept
Into Surgical	Dietary	0.011	0	*	--
Into Medical	Technician	2.950	1	0.100	Accept
Into Surgical	Technician	1.000	2	0.700	Accept
From Dietary	Non-professional Nursing	15.280	2	0.001	Reject
To Dietary	Non-professional Nursing	12.830	2	0.010	Reject
From Dietary	Dietary	34.810	4	0.001	Reject
To Dietary	Dietary	44.930	4	0.001	Reject
From Surgery	Professional Nursing	5.500	1	0.050	Reject
To Surgery	Professional Nursing	1.690	1	0.200	Accept
From Surgery	Non-professional Nursing	51.000	5	0.001	Reject
To Surgery	Non-professional Nursing	117.660	5	0.001	Reject
From Central Supply	Non-professional Nursing	2.930	3	0.500	Accept
To Central Supply	Non-professional Nursing	5.450	2	0.100	Accept
From Central Supply	Technician	0.840	1	0.500	Accept
To Central Supply	Technician	3.210	2	0.200	Accept
From Radiology	Non-professional Nursing	7.940	3	0.050	Reject
To Radiology	Non-professional Nursing	18.380	3	0.001	Reject
From Housekeeping	Housekeeping	4.790	3	0.200	Accept
To Housekeeping	Housekeeping	3.890	3	0.300	Accept
From Laboratory	Non-professional Nursing	2.620	1	0.200	Accept
To Laboratory	Non-professional Nursing	5.070	1	0.050	Reject

Table 15. Summary Results of Goodness of Fit Tests for the Poisson Distribution (Concluded)

Origin or Destination	Personnel Classification	Chi-Square Value	d.f.	Level of Significance	Conclusion
From Laboratory	Technician	1.730	2	0.500	Accept
To Laboratory	Technician	0.593	2	0.800	Accept
From Laundry	Non-professional Nursing	0.156	1	0.700	Accept
To Laundry	Non-professional Nursing	1.350	1	0.300	Accept
From Pharmacy	Professional Nursing	0.020	0	*	--
To Pharmacy	Professional Nursing	0.054	0	*	--
From Pharmacy	Non-professional Nursing	0.193	1	0.700	Accept
To Pharmacy	Non-professional Nursing	1.848	1	0.200	Accept
From Pharmacy	Technician	0.000	0	*	--
To Pharmacy	Technician	0.026	0	*	--
From Emergency	Professional Nursing	0.430	0	*	--
To Emergency	Professional Nursing	0.140	0	*	--
From Emergency	Non-professional Nursing	0.800	1	0.500	Accept
To Emergency	Non-professional Nursing	0.130	1	0.800	Accept
From Emergency	Technician	1.000	0	*	--
To Emergency	Technician	2.110	0	*	--

*There were not enough degrees of freedom to conduct a meaningful test.

value was significant at an α level of 0.05.

Of the 44 cases considered, the Poisson hypothesis was accepted in 24 cases, was rejected in 11, and there were nine cases in which the mean number of hourly trips was so low that there were not enough degrees of freedom to conduct a meaningful test. Of the 11 cases in which the Poisson hypothesis was rejected, there were two cases--trips into medical by housekeeping, and trips to laboratory by non-professional personnel--in which all other trips associated with those departments, including the counterpart of those rejected but in the opposite direction, were accepted as Poisson distributed. In view of this information, it was decided that it would not significantly reduce the accuracy of the overall model if these were assumed to be Poisson distributed. Similarly, of the 24 cases originally accepted as Poisson distributed, one case--trips by professional nursing to surgery--was rejected since its counterpart in the opposite direction, and all other trips associated with that department, were rejected originally. Finally, in those cases in which there were not enough degrees of freedom to conduct the test of significance, the computed Chi-Square values were so low that there is reason to believe that, if a sufficiently large number of observations had been conducted, the Poisson hypothesis would not have been rejected. It was, therefore, decided that it would not significantly reduce the accuracy of the overall model if these were assumed to be Poisson distributed. It should be noted that, in order to have enough degrees of freedom to conduct a meaningful test in those cases with a very low mean number of hourly trips, it would have been necessary to base the study on approximately 1000 hours, or 50 weeks of observations, instead of 96 hours on which it was actually based.

After these considerations, the number of personnel-department combinations for which the trips can be adequately described by a Poisson process are 34 out of a total of 44 considered originally. Those trips that cannot be described by a Poisson process are those for which the dietary, surgery, and radiology departments are the origin or destination. In an attempt to gain an insight into the nature of the traffic between these departments and the nursing unit, the department heads were interviewed regarding the frequency and purpose of the trips. The results of the interviews and the conclusions derived thereof are given below.

Dietary

It was found that the trips from dietary to the nursing units follow the schedule given below.

8:00 a.m.	Deliver Food Carts
9:00 a.m.	Pick Up Food Carts
10:30 a.m.	Pick Up Selective Menus
12:00 noon	Deliver Food Carts
1:00 p.m.	Pick Up Food Carts
1:30 p.m.	Pick Up Diet Sheets and Deliver Supplies
4:30 p.m.	Deliver Food Carts
5:30 p.m.	Pick Up Food Carts

There are three food carts delivered per nursing unit, and each cart requires one person for delivery and retrieval. With this information and the above schedule, the number of trips between the nursing units and the dietary department can be predicted rather accurately. This indicates that the number of trips between the nursing unit and the dietary department by dietary personnel is a deterministic rather than a stochastic variable. The trips by non-professional nursing between dietary and the units occur whenever a patient misses his meal at the regular time and must have it at irregular hours. Although the number of these trips would vary randomly from day to day, they would not occur randomly within each day but would tend to occur one to two hours after the regularly scheduled meals.

Surgery

It was found that South Fulton has a very busy surgical suite, with elective surgery being scheduled as much as six weeks in advance. In addition, it is very tightly scheduled, as evidenced by the typical weekly schedule shown in Figure 5. The "X" in each square indicates a procedure is scheduled to begin at the time indicated in the appropriate room. The trips between the surgical suite and the units by non-professional nursing personnel have the objective of picking up patients who are going to undergo surgery, whereas the trips by professional nursing personnel have the objective of bringing the patients back to the unit after surgery. With this information and knowledge of the surgery schedule, the number of trips between the surgical suite and the units by these two categories of personnel can be predicted quite accurately. This indicates that the trips are deterministic rather than stochastic in nature.

Radiology

The interview with the Radiology department head failed to reveal a schedule similar to the ones existing in the Dietary and Surgery Departments, except for the fact that the department tries to finish all the in-patient x-rays prior to 12:00 noon. The department head indicated that

	Monday					Tuesday					Wednesday					Thursday					Friday				
Room / Time	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
8:00 a.m.		X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X
8:30 a.m.														X					X	X					
9:00 a.m.		X	X	X	X					X	X	X	X	X			X	X		X				X	X
9:30 a.m.							X		X										X	X					
10:00 a.m.		X		X	X					X	X	X		X					X	X		X			X
10:30 a.m.					X			X															X		
11:00 a.m.				X						X							X					X			
11:30 a.m.					X																				
12:00 noon																	X								
12:30 p.m.					X				X											X					
1:00 p.m.		X		X				X		X					X		X								
1:30 p.m.																									
2:00 p.m.																									

Figure 5. Typical Weekly Surgery Schedule, South Fulton Hospital

the department load was highly variable. The trips between Radiology and the units by non-professional nursing have the purpose of picking up the patient, taking him to the department for his examination, and bringing him back to the unit. It appears that the combination of highly variable patient load and rapid morning scheduling results in trips which, even though they satisfy random needs, could be better described as some function of the patient load instead of as a random process. It has already been determined that the number of trips cannot be predicted with accuracy using the three-way patient classification or the size of the nursing unit staff. The development of additional deterministic predictors is beyond the scope of this study.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The conclusions derived from this study are the following.

1. Forty-five percent of all the departments of the hospital account for 75 percent of the nursing units' incoming and outgoing traffic by hospital personnel. The departments that account for this percentage are the other nursing units, dietary, surgery, central supply, radiology, housekeeping, laboratory, laundry, pharmacy, and emergency.

2. The personnel categories accounting for the majority of the traffic between the nursing units and the departments are non-professional nursing personnel accounting for 31 percent of the traffic and technicians, accounting for 13 percent of the traffic. Volunteers account for about one-fifth (21 percent) of the traffic.

3. The patient census categorized by the degree of care needed (total care, partial care, or self-care) is not a good predictor of traffic frequencies.

4. The size of the nursing unit staff, categorized by professional and non-professional nursing personnel, is not a good predictor of traffic frequencies by these two personnel categories.

5. The number of trips between the nursing units and the majority of the departments can be described reasonably well by a Poisson process. Those departments for which the trips cannot be adequately described by the Poisson model are surgery, radiology, and dietary. It is likely that

the trips between these departments and the nursing units are deterministic rather than stochastic.

Significance of the Results

The stochastic description of traffic between the nursing unit and other important functional centers permits quantitative treatment of a number of considerations important in hospital planning and in managerial decision making. Two examples discussed below illustrate some possible uses of the results obtained herein.

Calculation of Probabilities of Traffic Densities

Let us assume that a corridor is being planned which will be used primarily by persons going to central supply and to the clinical laboratory. Such a corridor can be observed in the first floor plan of the study hospital, Figure 7. The hospital designer is interested in knowing the number of persons utilizing this corridor in order to plan for aisle width, floor coverings, provisions for noise levels, and the like. The results of this study indicate that the majority of the trips between the nursing units and these two departments are accounted for by non-professional nursing and technician personnel. Specifically, the probabilities of the number of trips per hour are as follows:

Probability of K trips by non-professional nursing personnel to central supply

$$P(K) = \frac{e^{-1.0}\,(1.0)^{K}}{K!}\ ; \quad K = 0,\ 1,\ 2,\ \ldots$$

Probability of K trips by technician personnel to central supply

$$P(K) = \frac{e^{-0.5}\ (0.5)^K}{K!} \ ; \quad K = 0, 1, 2, \ldots$$

Probability of K trips by non-professional nursing personnel to the laboratory

$$P(K) = \frac{e^{-0.4}\ (0.4)^K}{K!} \ ; \quad K = 0, 1, 2, \ldots$$

Probability of K trips by technician personnel to the laboratory

$$P(K) = \frac{e^{-0.8}\ (0.8)^K}{K!} \ ; \quad K = 0, 1, 2, \ldots$$

Since these personnel categories perform different tasks when traveling to these departments, it can be assumed that the number of trips for each category is independent of the number of trips for the others; therefore, the probability density function of N, the total number of trips per hour from the nursing units through the aforementioned corridor, is Poisson with a mean equal to the sum of the means of each of the individual cases, that is

$$P(N) = \frac{e^{-2.7}\ (2.7)^N}{N!} \ ; \quad N = 1, 2, \ldots$$

and the probability that there will be n or more trips during an hour is given by

$$P(N \geq n) = \sum_{i=n}^{\infty} \frac{e^{-2.7}\,(2.7)^{i}}{i!}$$

This relationship enables us to calculate the probabilities of various traffic densities. Table 16, a tabular presentation of the foregoing relationship, indicates that a traffic density of five or more trips per hour will occur approximately 15 percent of the time, and a traffic density of six or more trips per hour will occur approximately seven percent of the time. The simplicity of the stochastic traffic descriptor permits extension of the formula for P(N) to include as many departmental interrelationships and personnel classes as desired.

Calculation of Staffing Requirements

An application of the results of this study to managerial decision making is that of determining the staff requirements to insure adequate patient care. To illustrate this application, let us assume that it takes an average of 20 minutes for a trip from the nursing units to central supply. This study indicated that the trips to central supply by nonprofessional nursing personnel are Poisson with a mean of one trip per hour, or 0.333 trips per 20 minute interval. If management policy states that there shall be at least one aide in the unit 95 percent of the time, the results of the study indicate that two aides will satisfy this policy adequately insofar as trips to central supply are considered, since the probability of two or more trips occurring in a 20 minute interval is only 0.04. It is axiomatic that aides travel to other departments in addition to central supply; the foregoing example purposefully considered only one

Table 16. Probabilities of Traffic Density of n or More

N	$P(N \geq n)$
0	1.000
1	0.939
2	0.767
3	0.531
4	0.308
5	0.152
6	0.065
7	0.024
8	0.008
9	0.002
10	0.001

department for the sake of simplicity, and the results can be extended to a combination of departments by simple addition of means.

Other applications of the results might be the calculation of the probability that certain number of persons will be traveling to the nursing units at the same instant, which would have a bearing on elevator usage and could be used in planning for the number of elevators, stairs, and other modes of travel, following a procedure similar to the one presented in the first example of this section. The stochastic description of travel could also be used in simulating the effect of labor saving devices, such as dumbwaiters and pneumatic tubes, on travel, congestion, and the like.

The results of this study are relevant to South Fulton Hospital, the study hospital, in several ways. The identification of important functional centers and personnel categories achieved should be immediately useful to hospital management in identifying potential areas of misdirected effort. No attempt was made in this study to ascertain whether the functional centers and personnel categories identified as important were intended to be important by hospital management. Another result of immediate relevance to South Fulton's management is the application to the calculation of staffing requirements illustrated above.

Souder's results (18) indicated there may be an underlying uniformity in hospital traffic patterns, as evidenced by the fact that the traffic patterns of the two hospitals studied were remarkably alike even though the hospitals studied were of different design and were located at opposite ends of the country. This suggests that the results of this study, even though developed at only one hospital, will have general applicability. The general method of procedure should be valid in all situations, however.

Suggestions for Further Study

This study describes the nature of interdepartmental traffic and, based on this description, predictions can be made about this phenomenon with reasonable accuracy. There are, however, certain phases of the phenomenon which remain unexplained. It is suggested that further investigation be conducted regarding those departments for which the trips could not be described by a Poisson process. The additional study should focus attention on good deterministic predictors for the travel frequencies between these departments and the nursing units. In particular, attention should be given to surgery and radiology, as it is believed that the trips to these departments are more affected by patient load than the trips to any other department.

It is further recommended that investigation be conducted regarding predictors for the parameter of the stochastic model describing the trips between the nursing units and other departments. The parameters used in this study were based on historical data, and if full benefit is to be gained from these results, means must be found to predict the parameters from variables such as hospital operating policy and the like. Once this predictive ability is achieved, measures of effectiveness such as the ones described in the section of significance of results can be calculated for projected hospitals.

Investigation should also be conducted in order to ascertain if the traffic between other functional centers, i.e., radiology-pharmacy, can be described by a Poisson process. The investigation of these relationships was beyond the scope of this study.

Finally, it is recommended that the stochastic descriptors developed be combined with labor and amortization costs to generate cost indices which can be utilized in evaluating the relative efficiencies of hospital layouts.

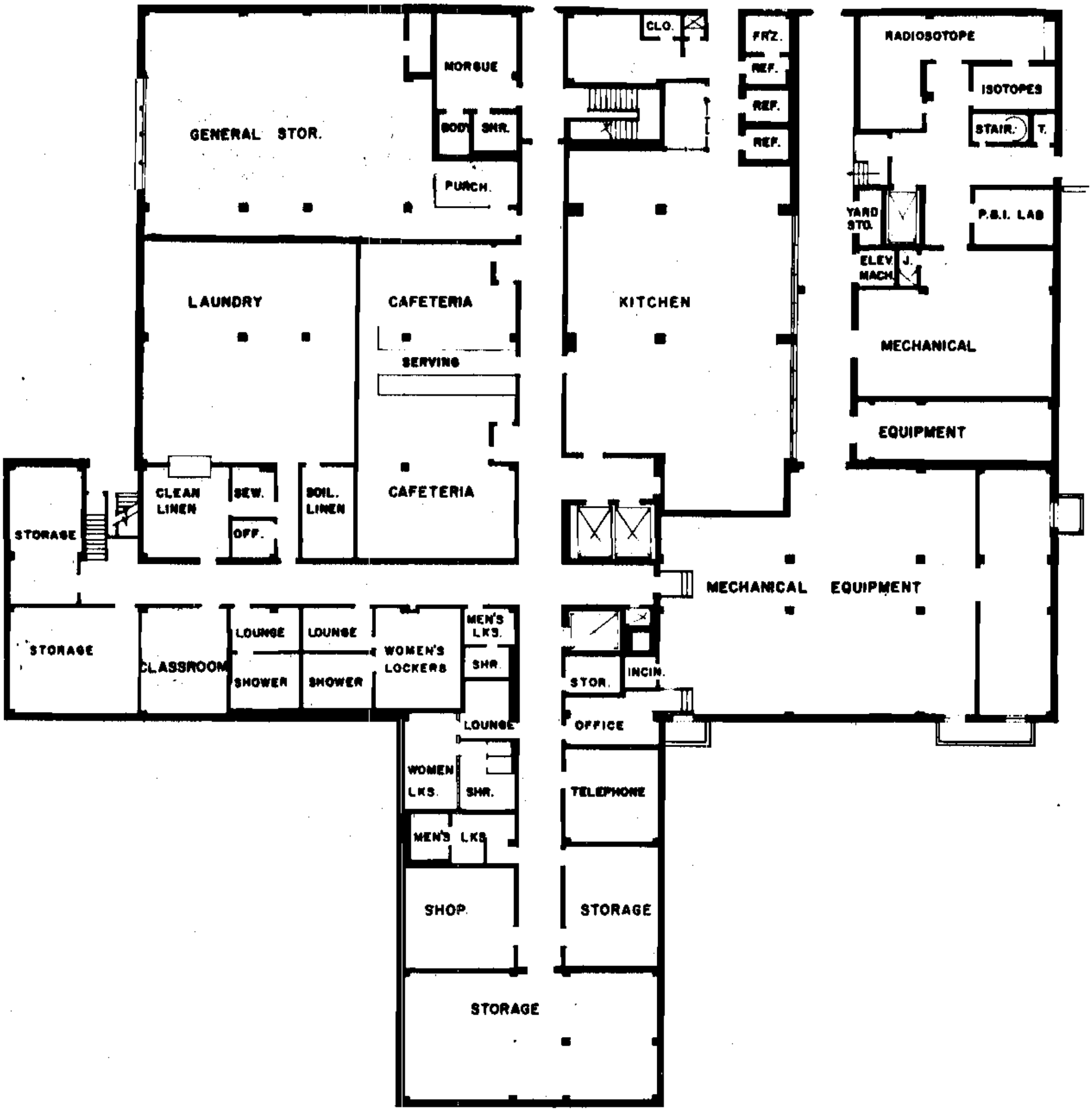
APPENDIX A

Table 17. Facilities, Services, and Staffing of South Fulton Hospital

Beds	152
Admissions per year	8900
Average census	135
Nursing units	4
Plan	Vertical, compact
Charity beds	Emergency only
Food service	Centralized
Pneumatic tube service	Yes
Direct dumbwaiter service, supply centers to nursing units	Yes
Elevators	3
<u>Services</u>	
BMR	No
Blood bank	No
Central supply	Open 7 days
Clinical laboratory	Yes
Dental department	No
Electrocardiograph	Yes
Electroencephalograph	Yes
Emergency	Principal on community
Chronic care	No
Intensive care	Yes
Laundry	Yes
Medical records	Yes
Medical staff library	Yes
Obstetrics	Yes
Occupational therapy	No

Table 17. Facilities, Services, and Staffing of South Fulton Hospital (Concluded)

Organized I.V.	No
Pediatrics	Yes
Outpatient	Small
Pharmacy	Yes
Physical therapy	No
Recovery room	Postanesthesia
Radiology	
Inpatient	Yes
Outpatient	Heavy
<u>Staffing</u>	
Attending physicians, active	Approximately 95
Residents and interns	0
Full time Radiologist	2
Full time Pathologist	2
Full time Anesthesiologist	4
Registered nurses	Approximately 76
Student nurses	0
Licensed practical nurses	Approximately 28
Student practical nurses	0
Nursing aides	Approximately 69
Orderlies	Approximately 7
Organized volunteers	Approximately 600

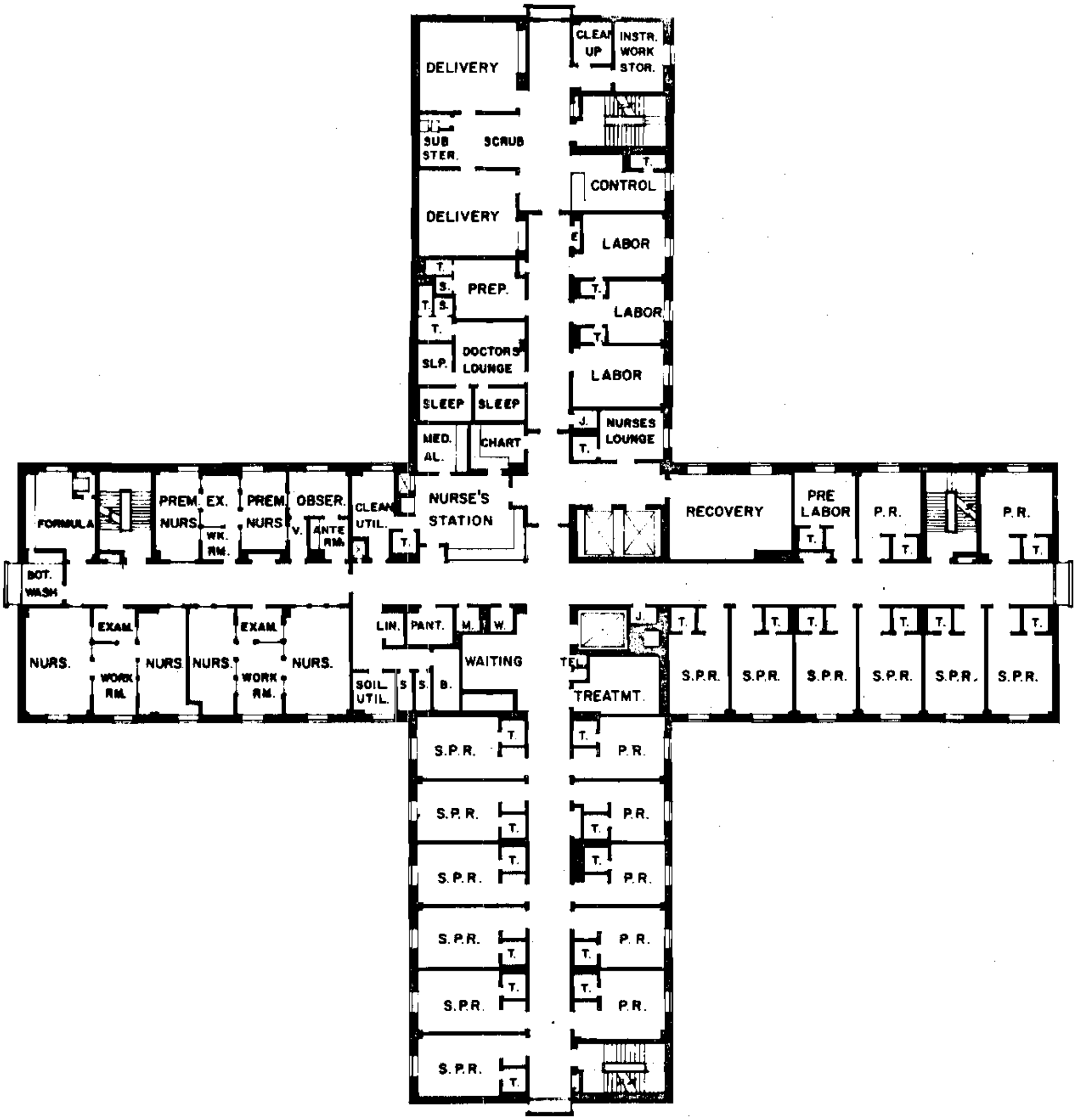


Scale: 1/32" = 1'0"

Figure 6. Ground Floor Plan, South Fulton Hospital

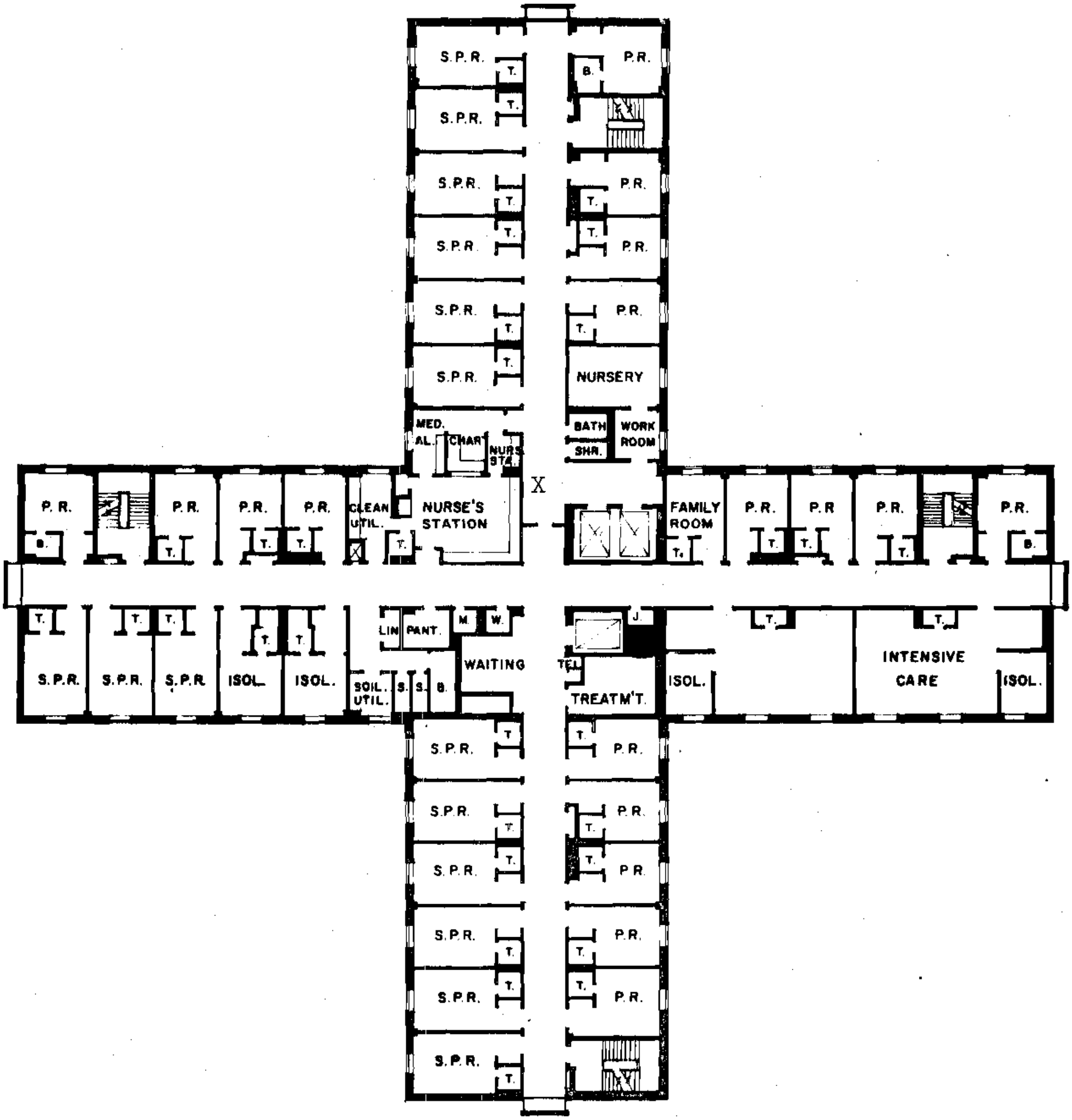
Scale: 1/32" = 1'0"

Figure 7. First Floor Plan, South Fulton Hospital



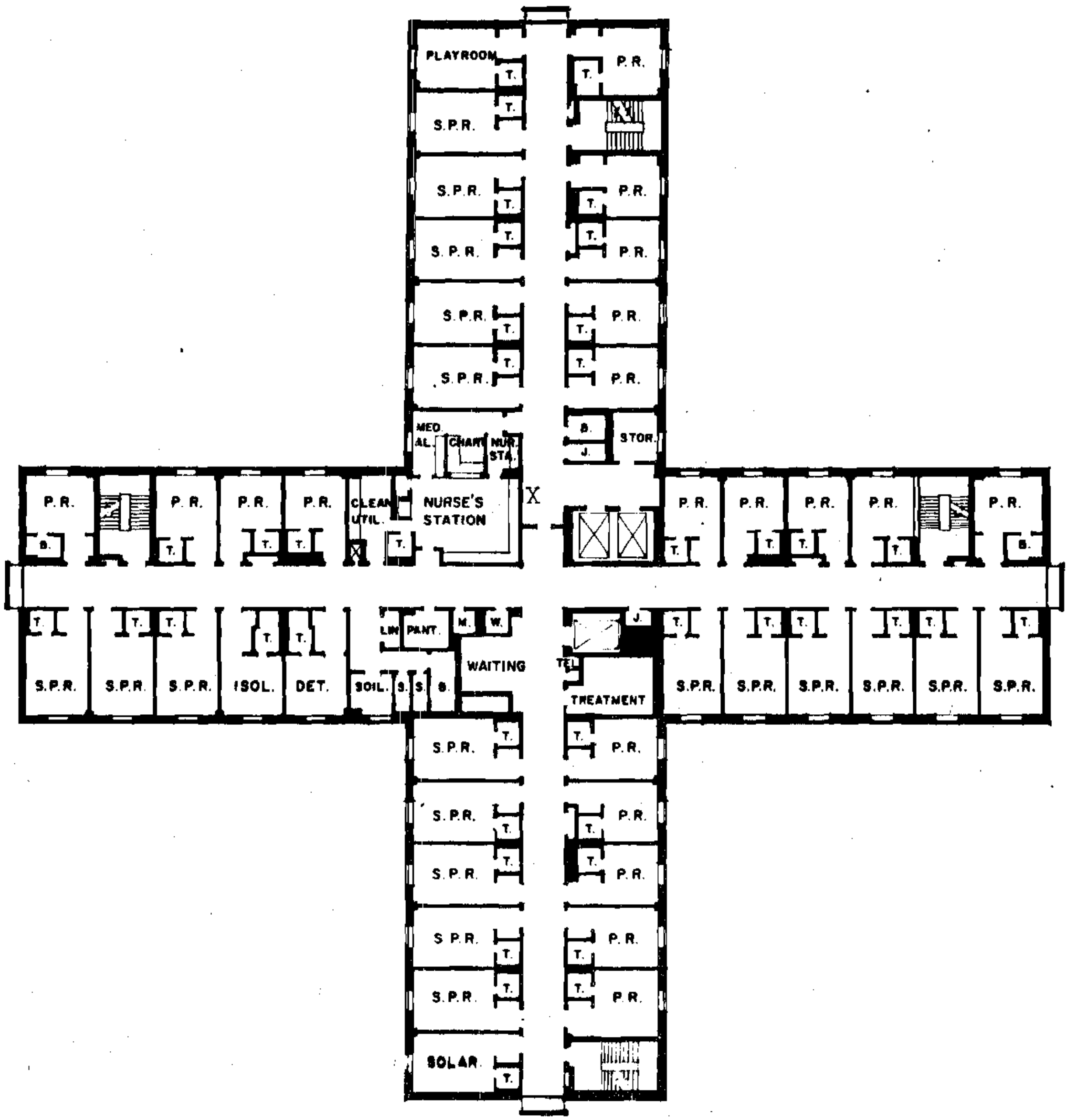
Scale: 1/32" = 1'0"

Figure 8. Second Floor Plan (Obstetrics and Delivery), South Fulton Hospital



Scale: 1/32" = 1'0"

Figure 9. Third Floor Plan (Surgical Unit), South Fulton Hospital



Scale: 1/32" = 1'0"

Figure 10. Fourth Floor Plan (Medical and Pediatrics Unit), South Fulton Hospital

Table 18. Schedule of Observations

Date	Place
Tuesday, August 9, 1966	Medical and Pediatrics
Wednesday, August 10, 1966	Surgical
Saturday, August 13, 1966	Medical and Pediatrics
Tuesday, August 16, 1966	Surgical
Wednesday, August 17, 1966	Medical and Pediatrics
Friday, August 26, 1966	Medical and Pediatrics
Saturday, August 27, 1966	Surgical
Tuesday, September 6, 1966	Surgical
Thursday, September 8, 1966	Medical and Pediatrics
Friday, September 9, 1966	Surgical
Monday, September 12, 1966	Medical and Pediatrics
Tuesday, September 13, 1966	Surgical
Wednesday, September 14, 1966	Medical and Pediatrics
Thursday, September 15, 1966	Surgical

Date: Time Period: Ward:

By To/From	Nursing RN	 LPN	 Aide	 Orderly	Volunteer	Doctor	Housekeeping	Maintenance	Dietary	W.C.	Other
Obstetrics											
Radiology											
Operating Room											
Pharmacy											
Dietary											
Laboratory											
Emergency											
Housekeeping											
Maintenance											
Central Supply											
Lounge											
Dining Room											
Medical Records											
Laundry											
Lobby & Admissions											
Business Office											
Nursing Service											

Figure 11. Sample Data Sheet

APPENDIX B

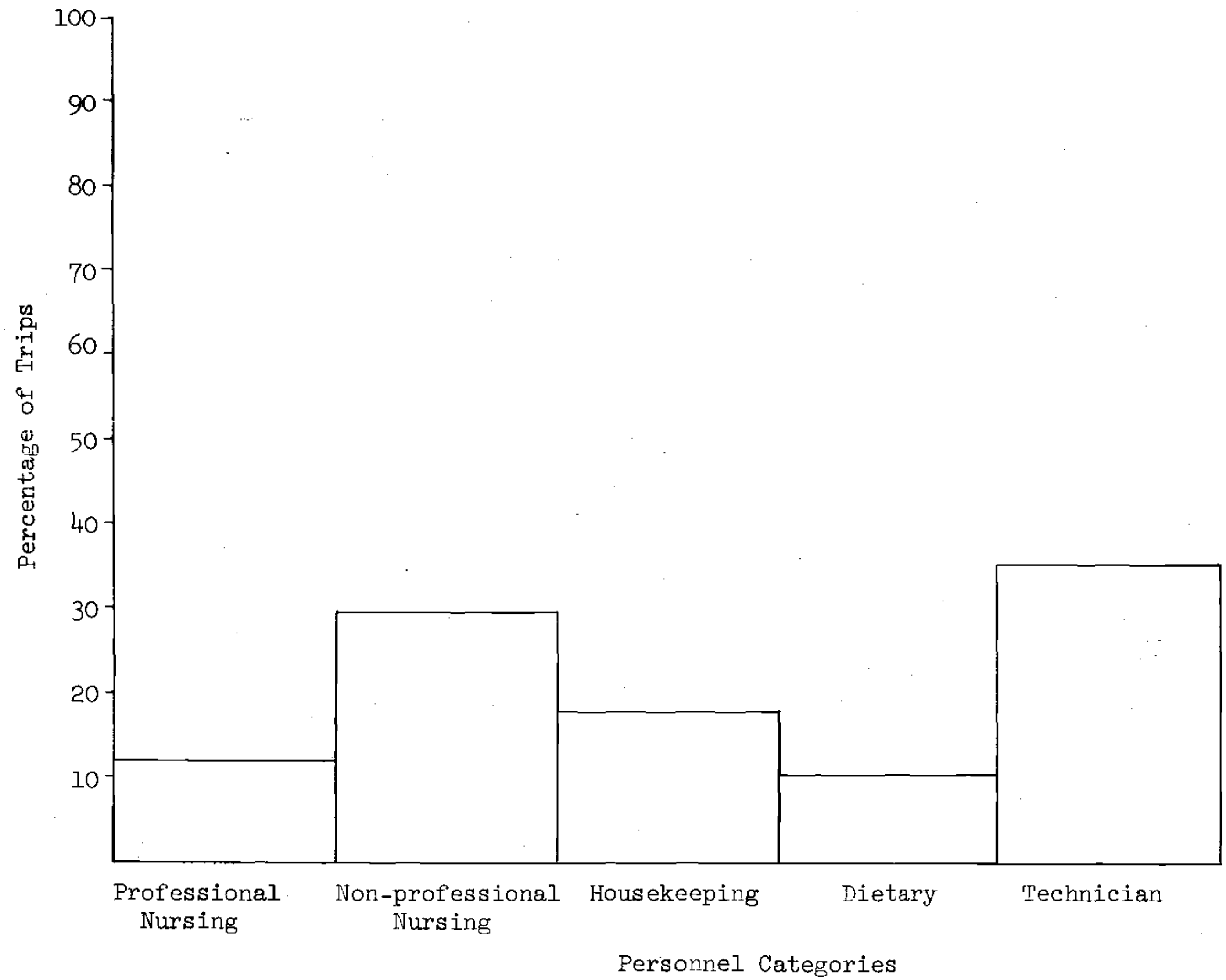


Figure 12. Department-Personnel Interaction: Nursing Units

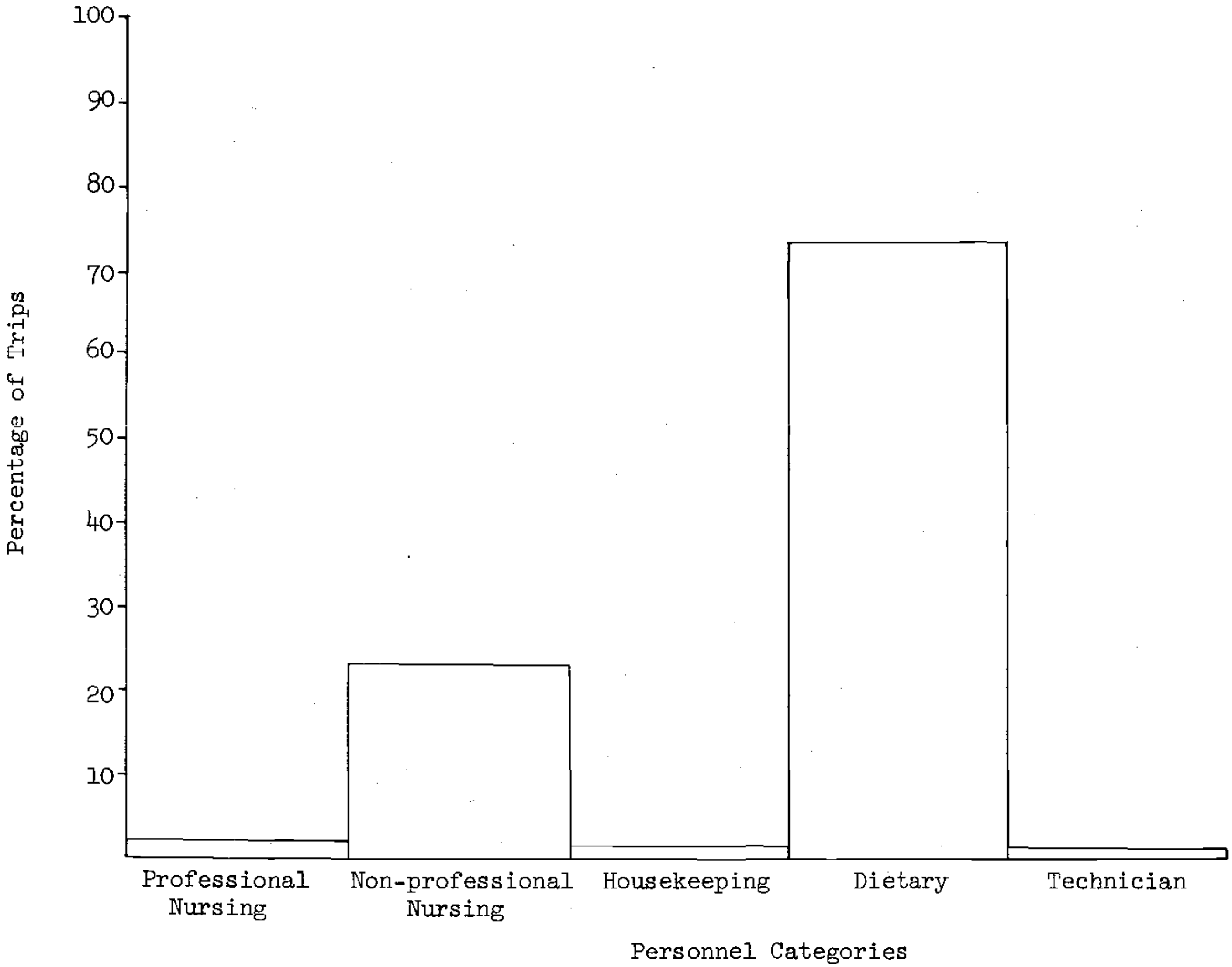


Figure 13. Department-Personnel Interaction: Dietary

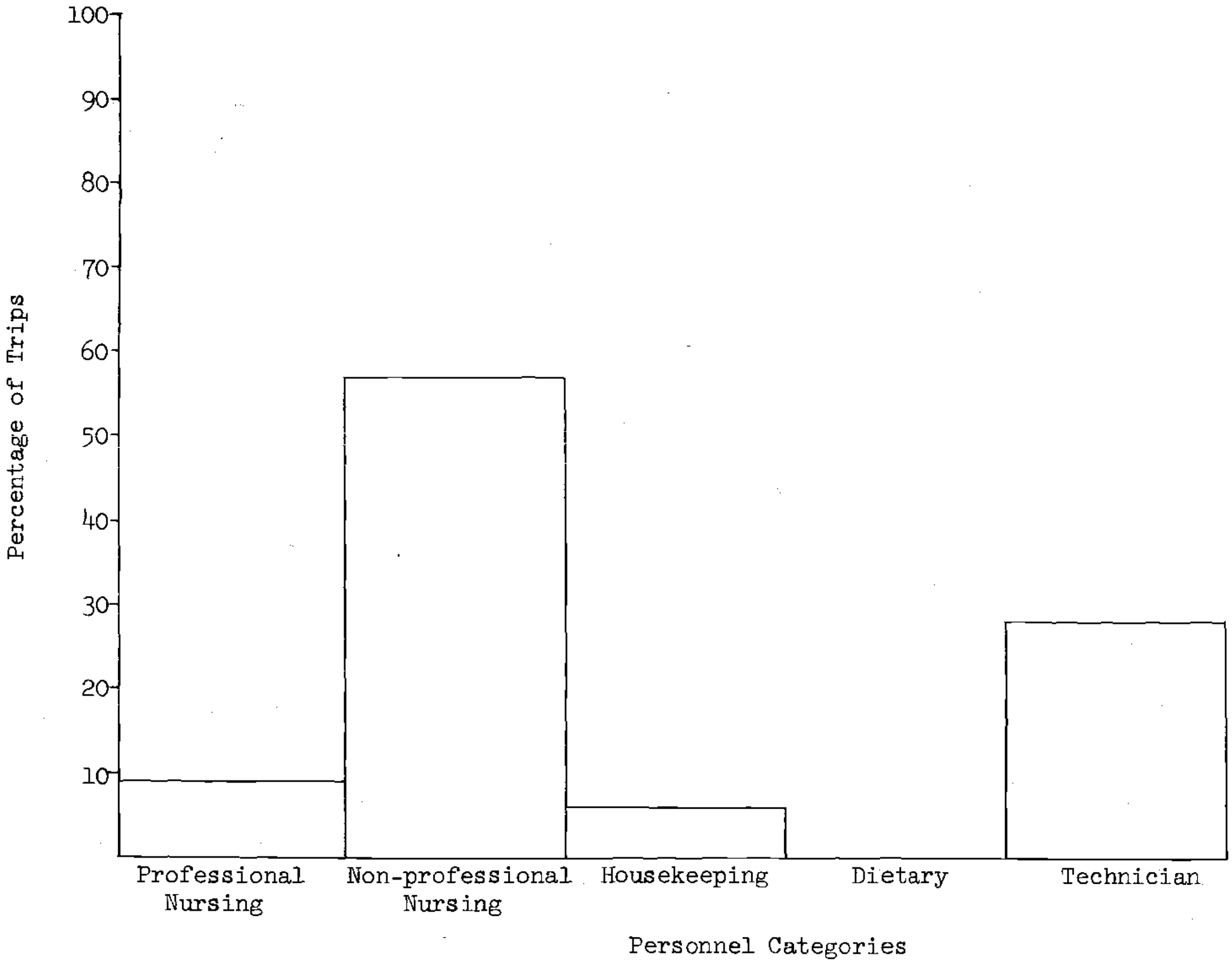


Figure 14. Department-Personnel Interaction: Central Supply

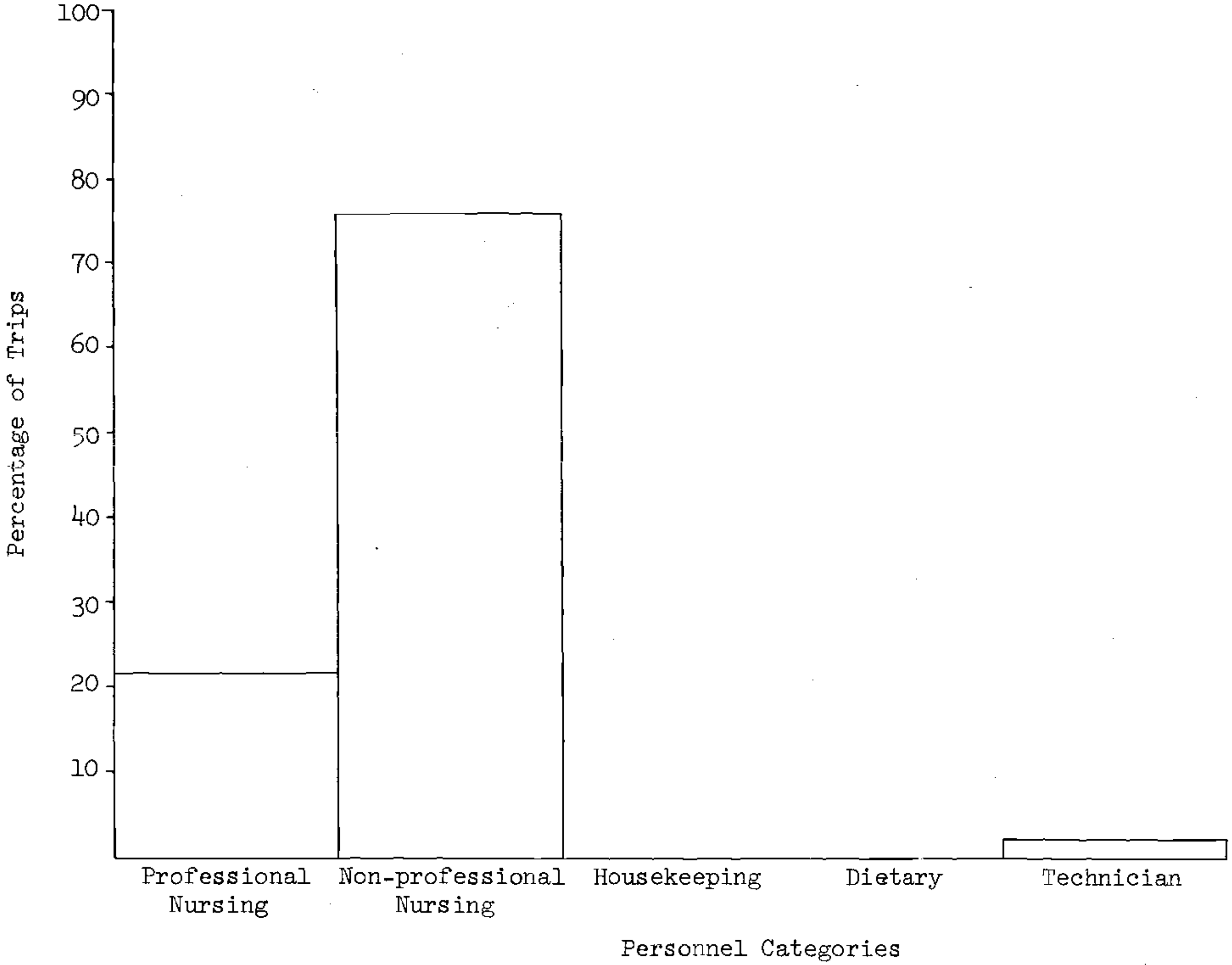


Figure 15. Department-Personnel Interaction: Operating Room

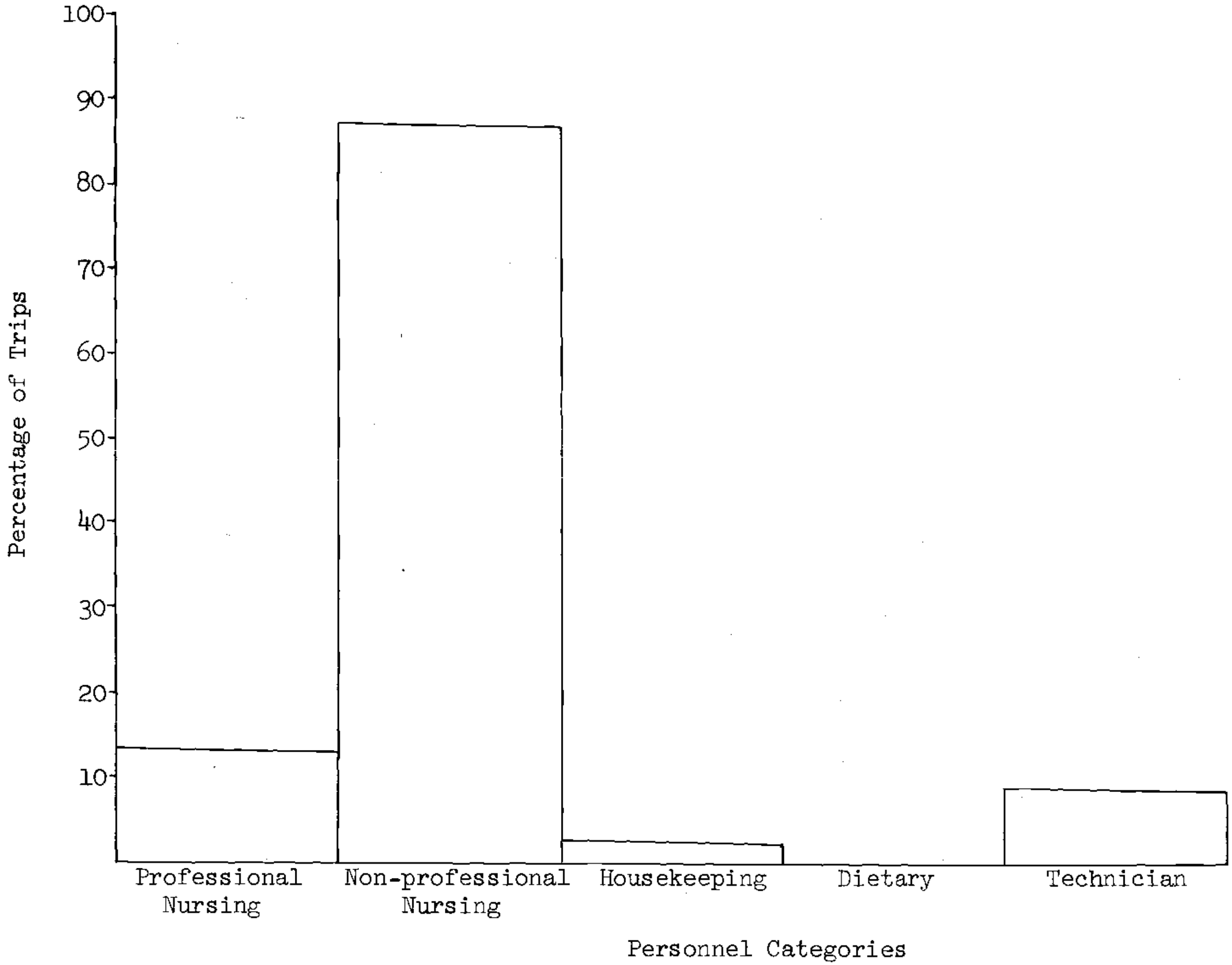


Figure 16. Department-Personnel Interaction: Radiology

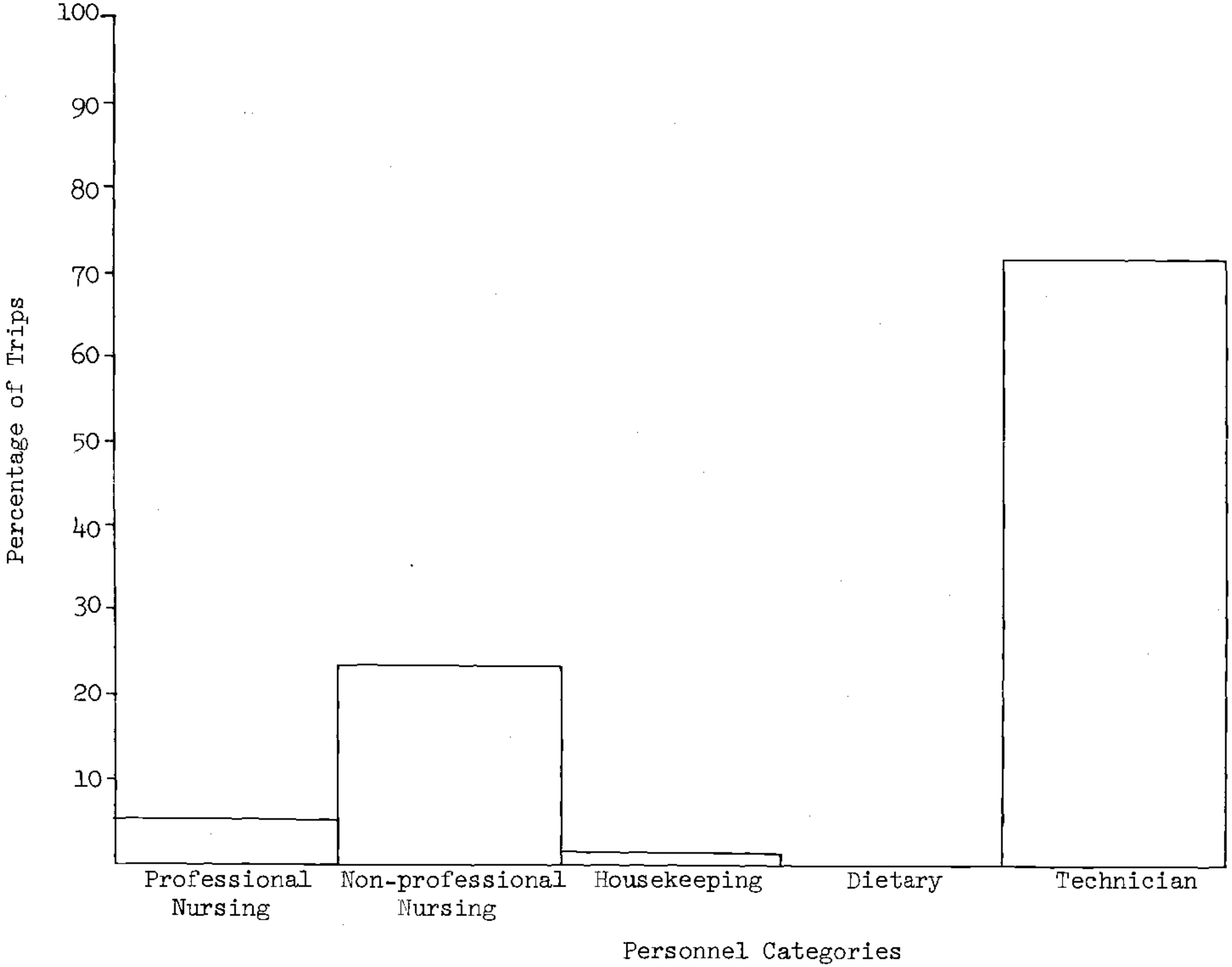


Figure 17. Department-Personnel Interaction: Laboratory

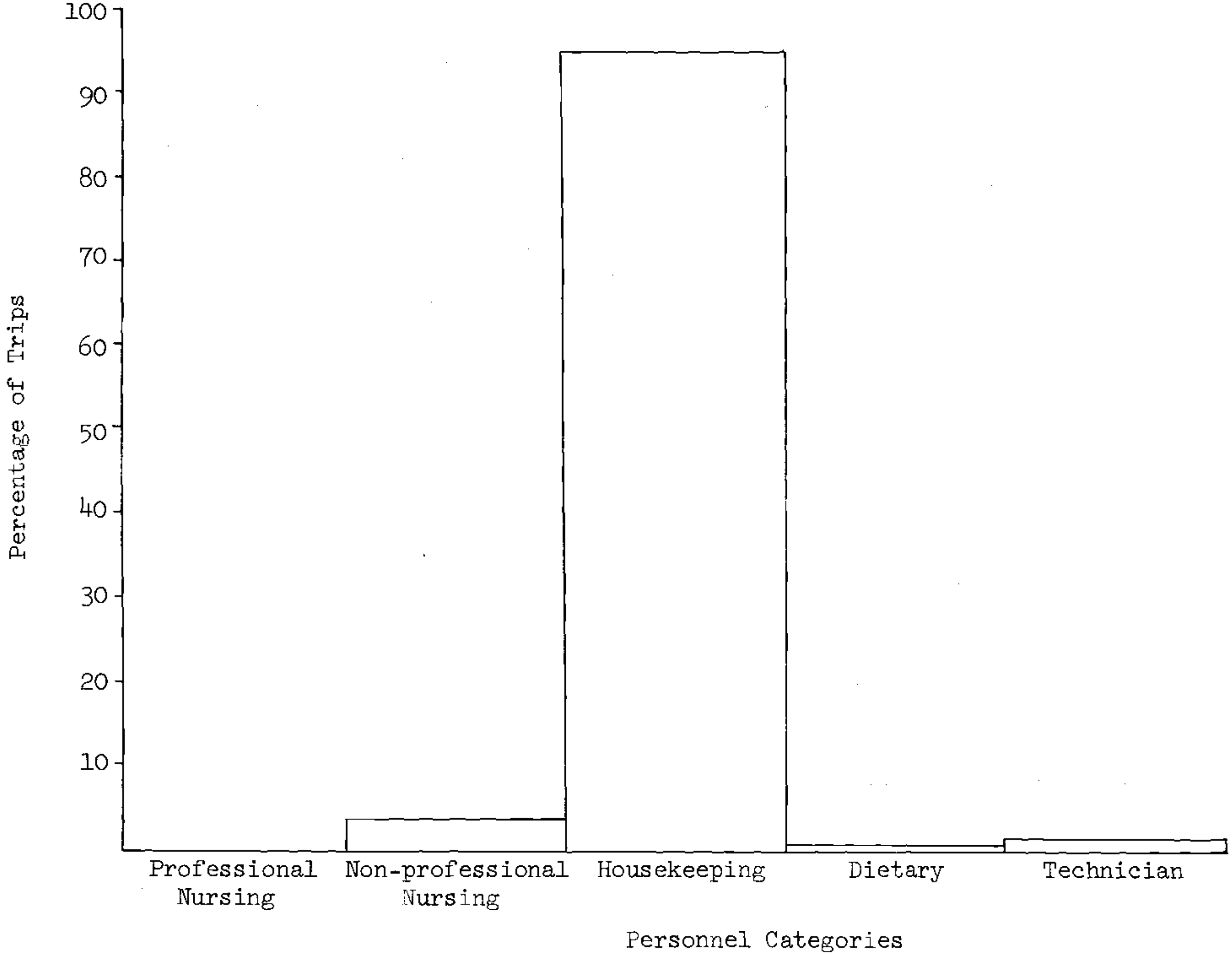


Figure 18. Department-Personnel Interaction: Housekeeping

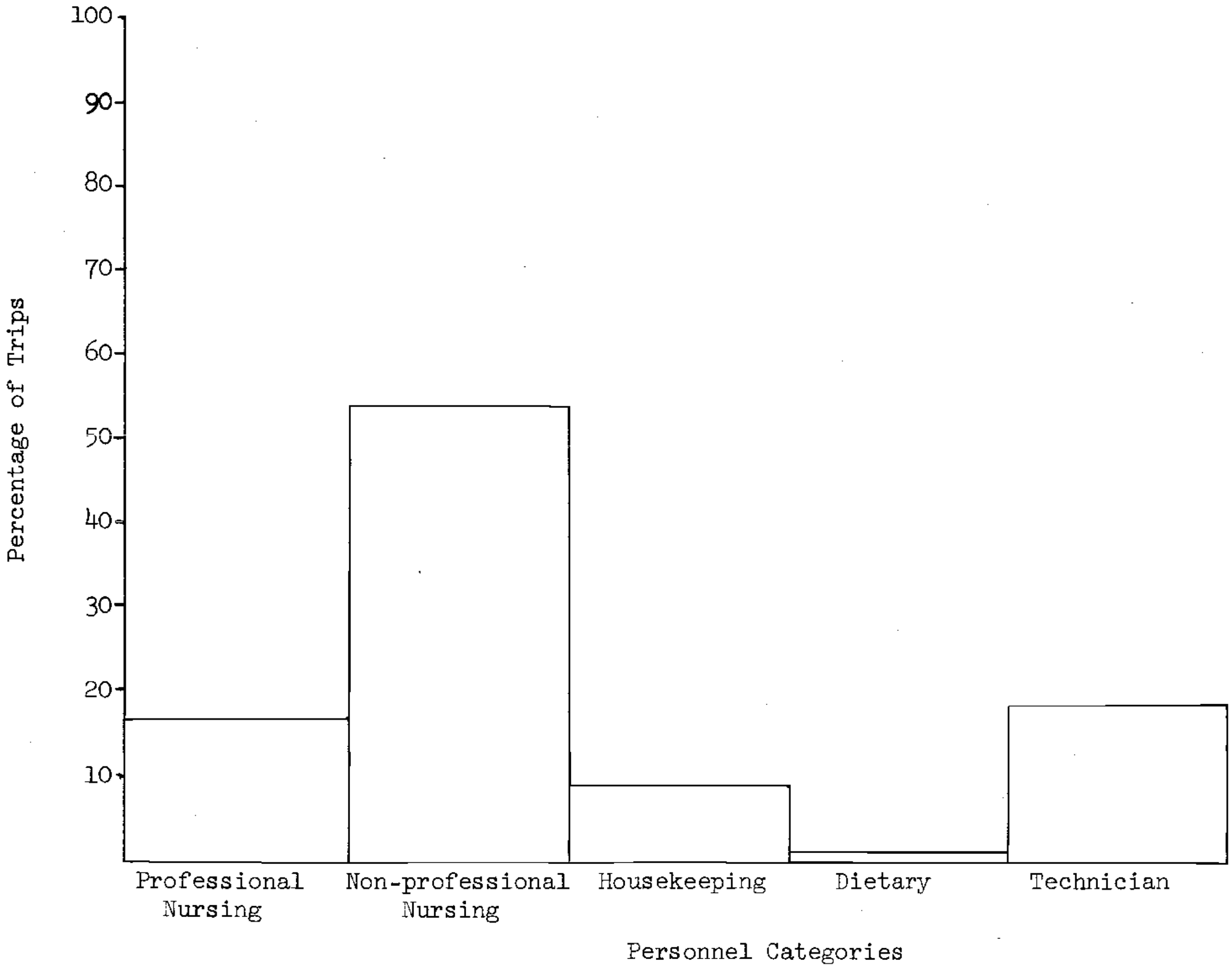


Figure 19. Department-Personnel Interaction: Emergency

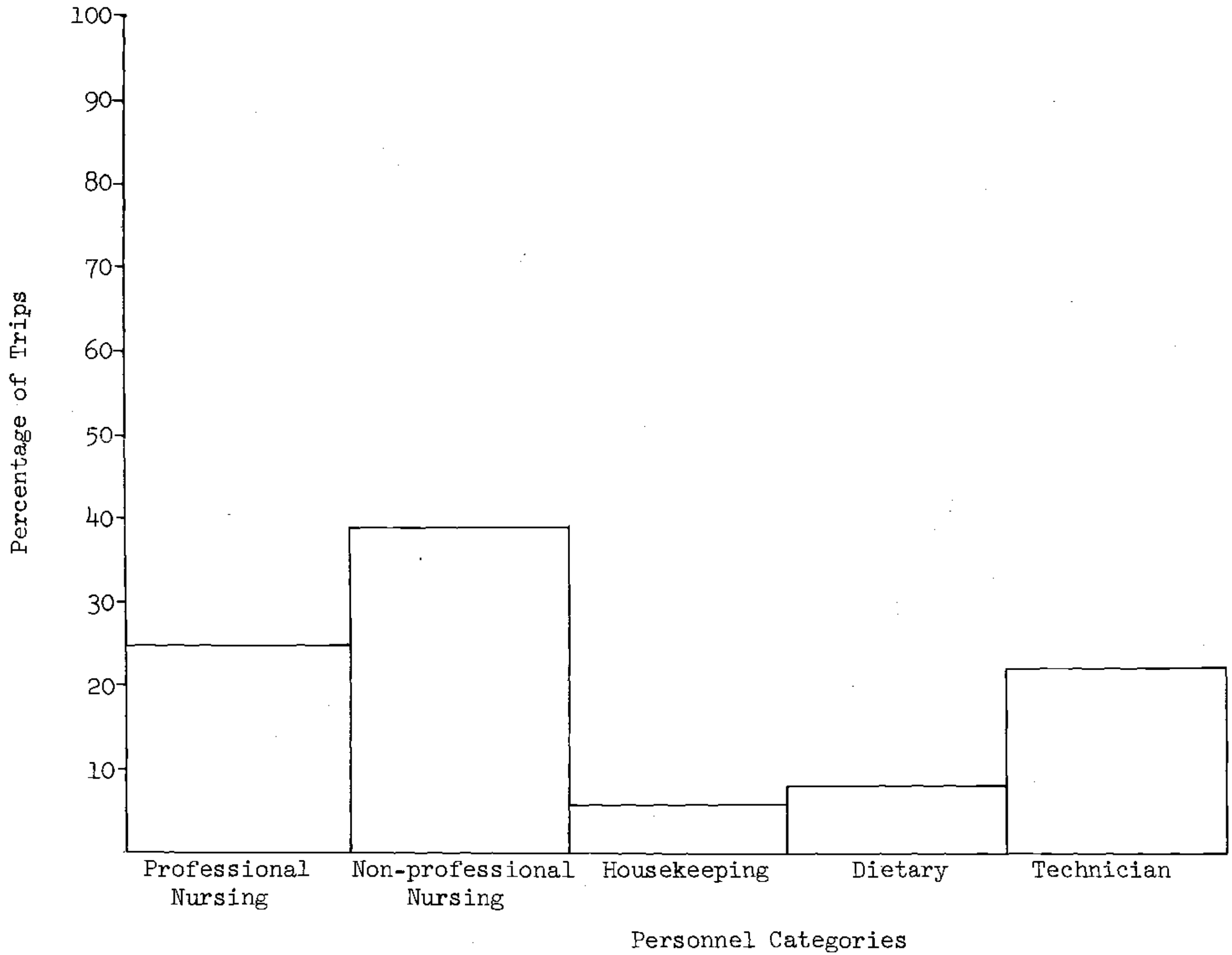


Figure 20. Department-Personnel Interaction: Pharmacy

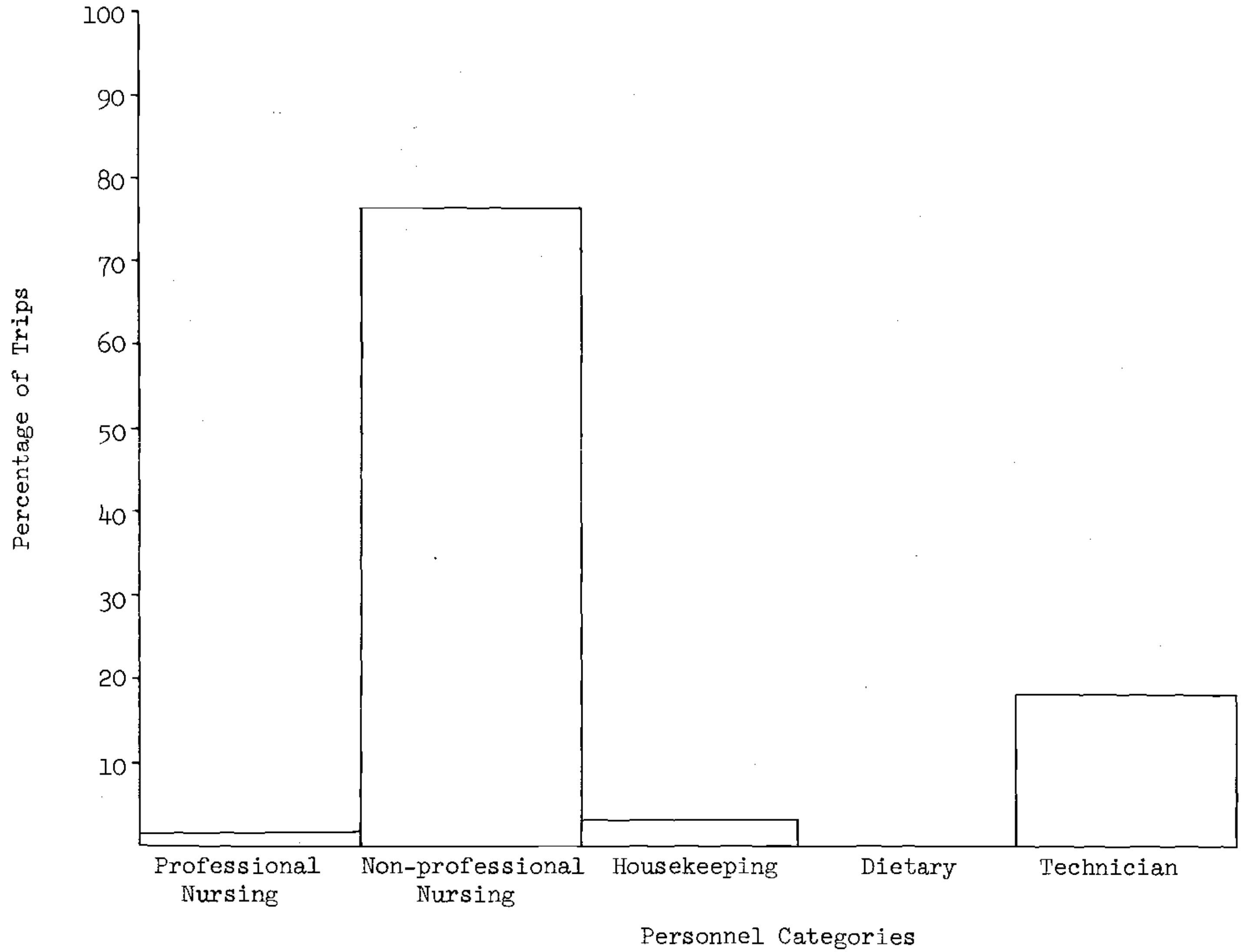


Figure 21. Department-Personnel Interaction: Laundry

APPENDIX C

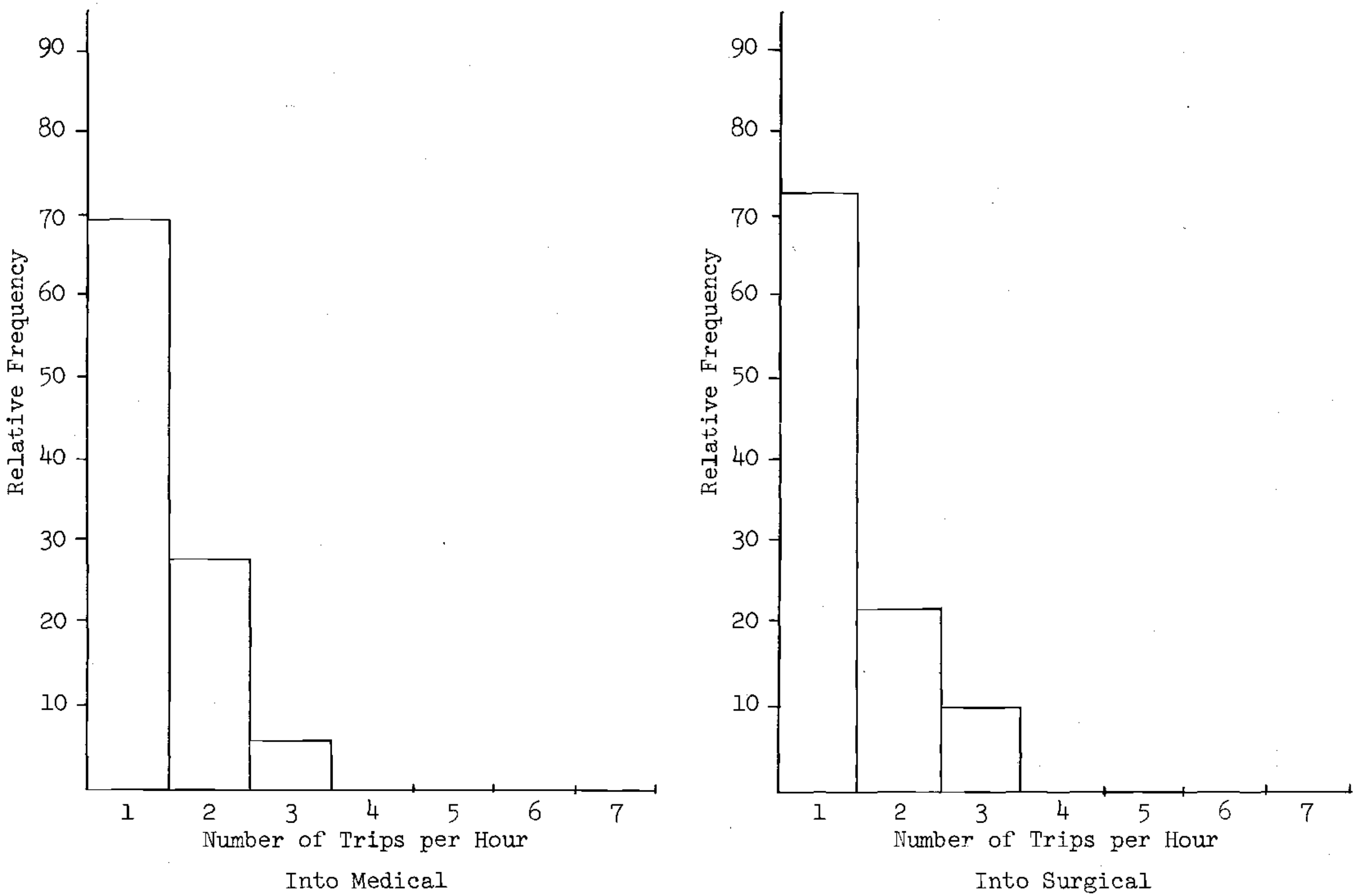


Figure 22. Trip Frequency Histograms: Nursing Units - Professional Nursing Personnel

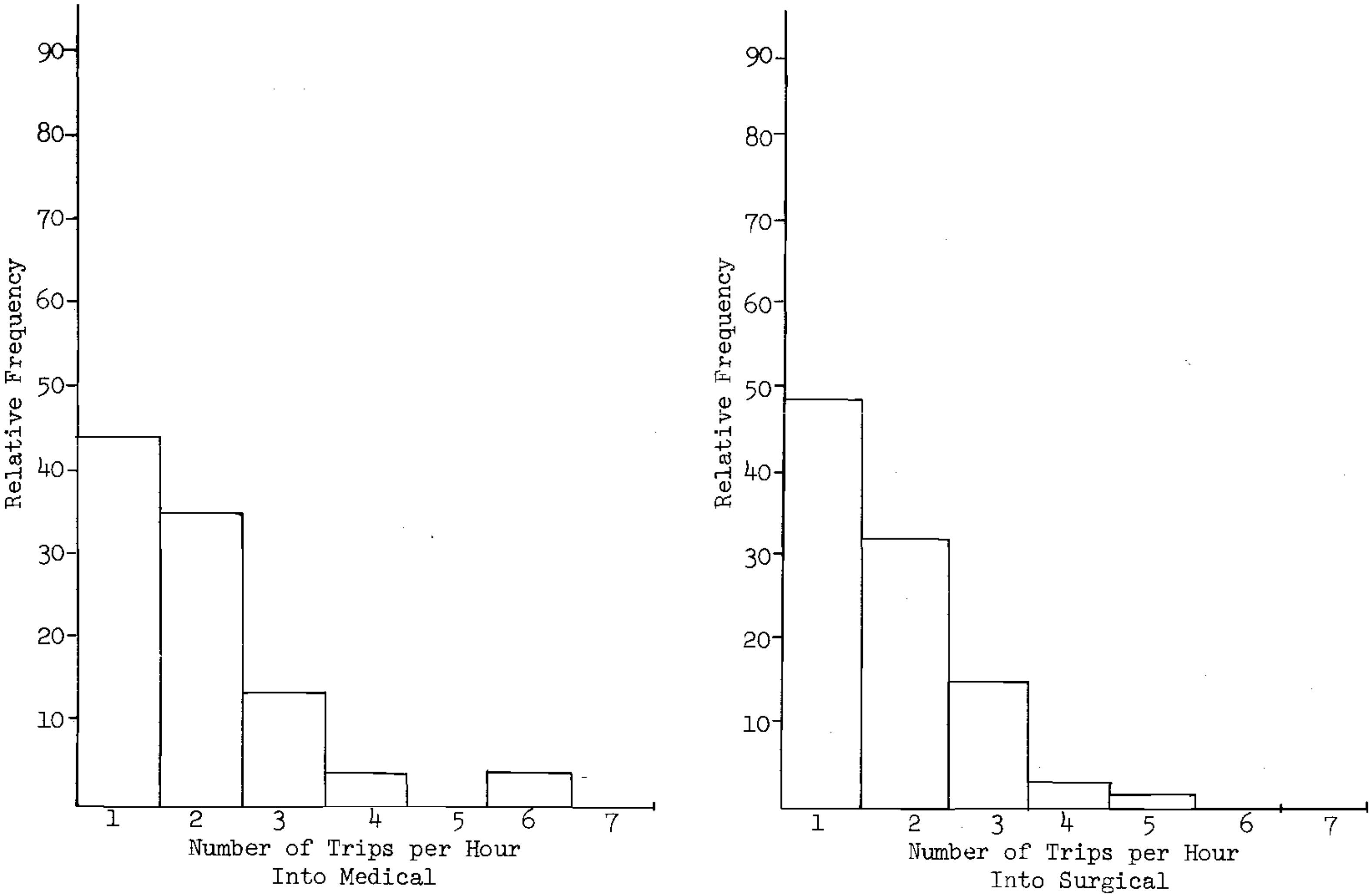


Figure 23. Trip Frequency Histograms: Nursing Units - Non-professional Nursing Personnel

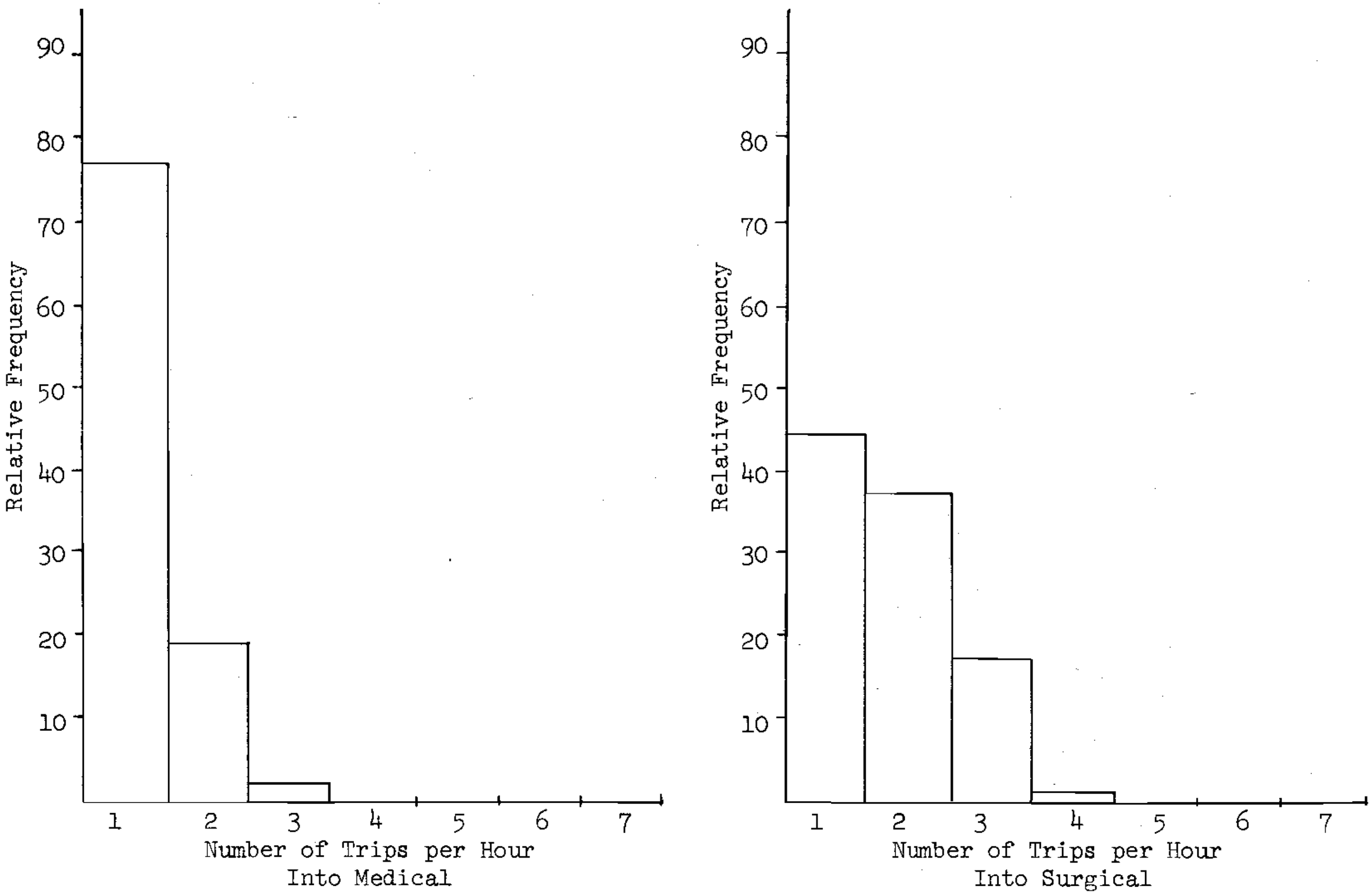


Figure 24. Trip Frequency Histograms: Nursing Units - Housekeeping Personnel

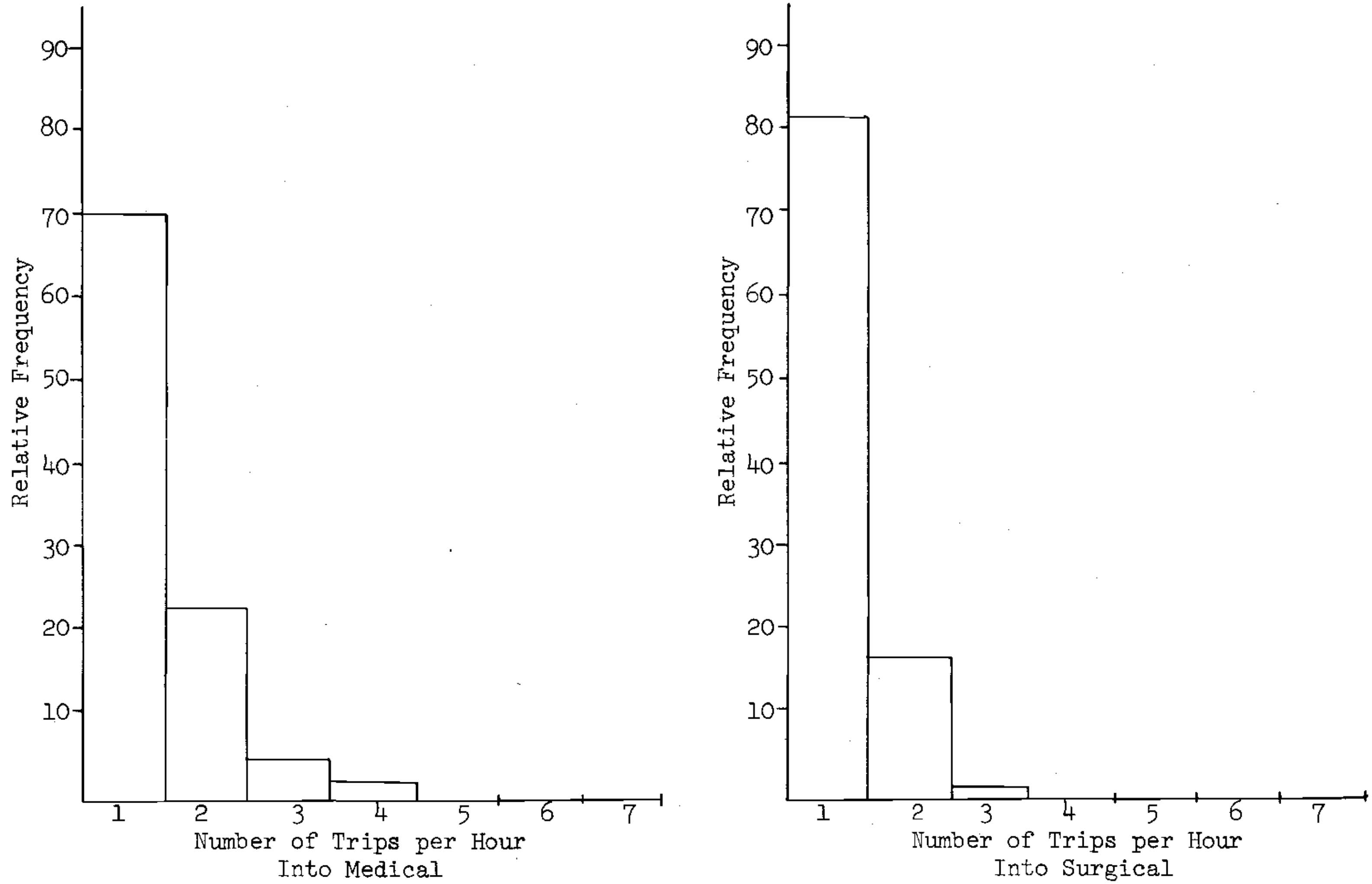


Figure 25. Trip Frequency Histograms: Nursing Units - Dietary Personnel

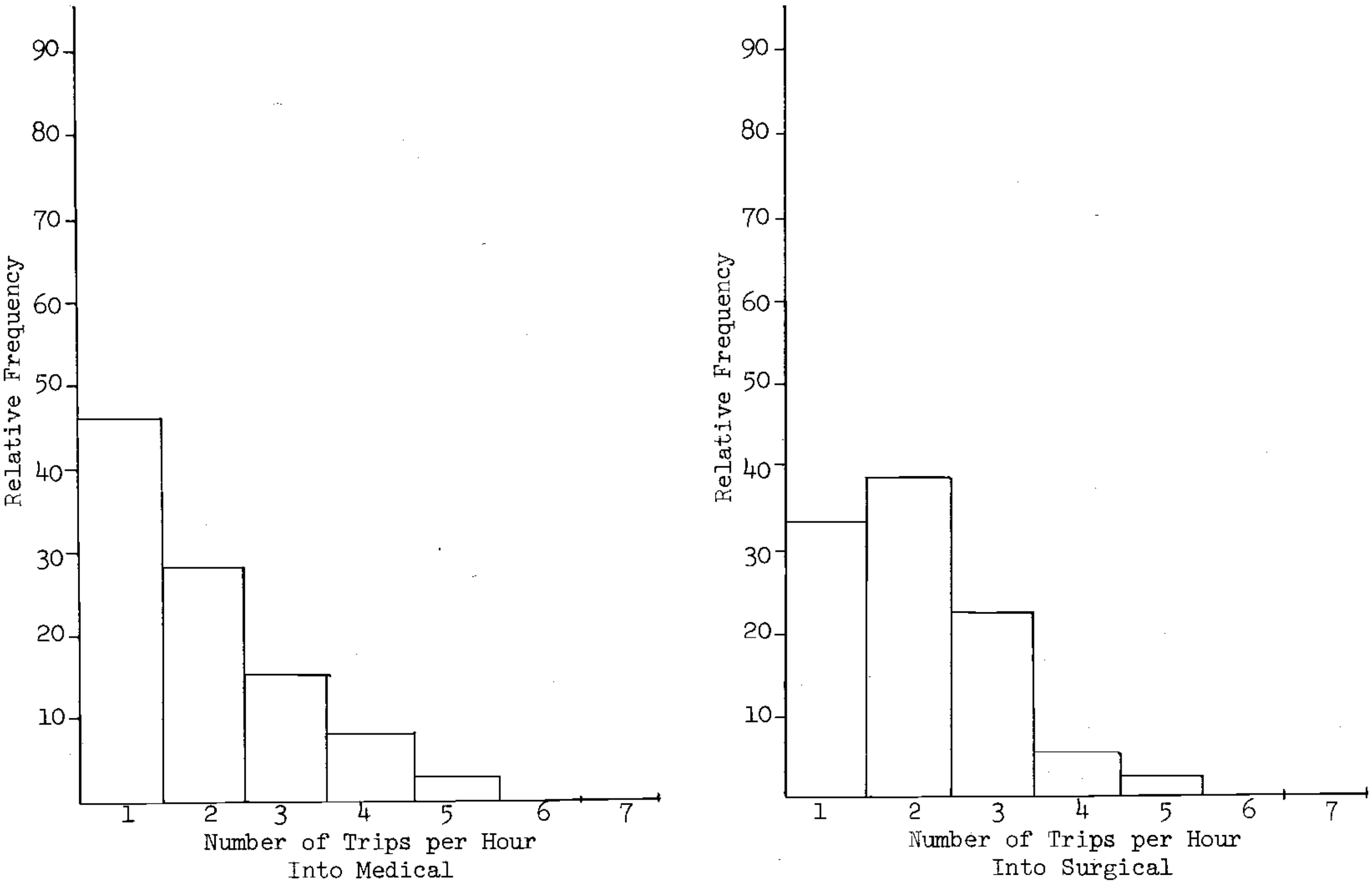


Figure 26. Trip Frequency Histograms: Nursing Units - Technician Personnel

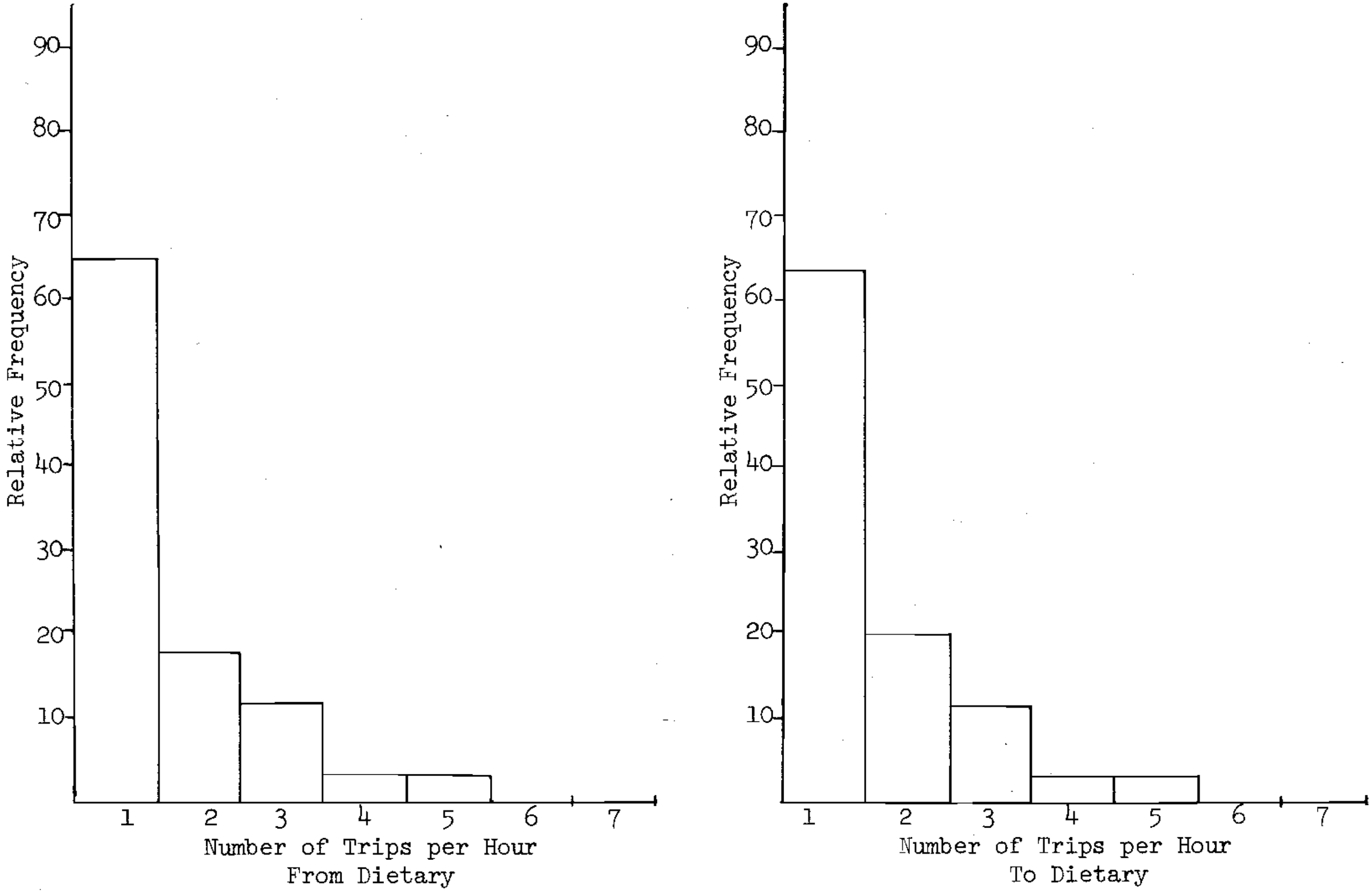


Figure 27. Trip Frequency Histograms: Dietary - Non-professional Nursing Personnel

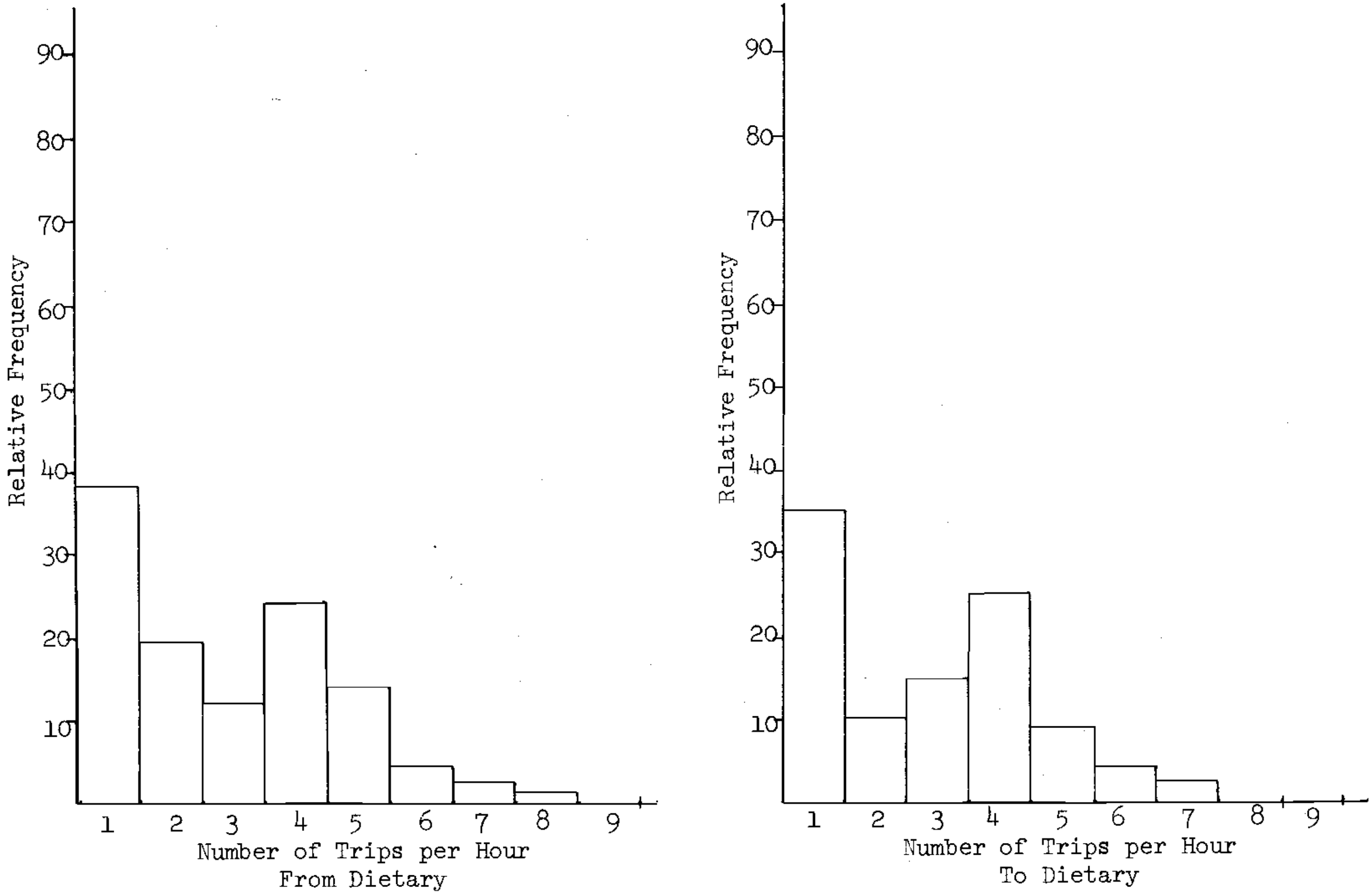


Figure 28. Trip Frequency Histograms: Dietary Department - Dietary Personnel

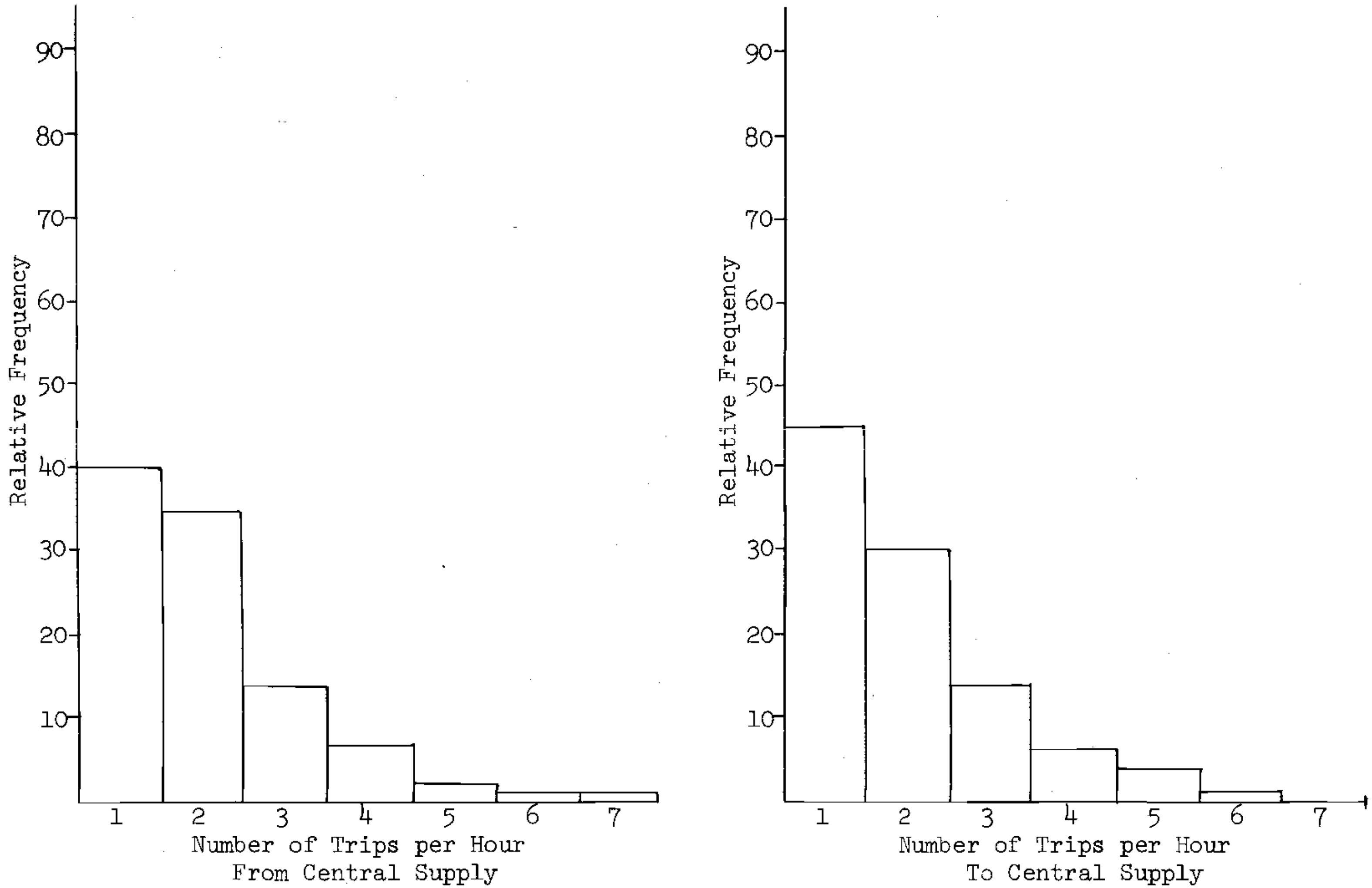
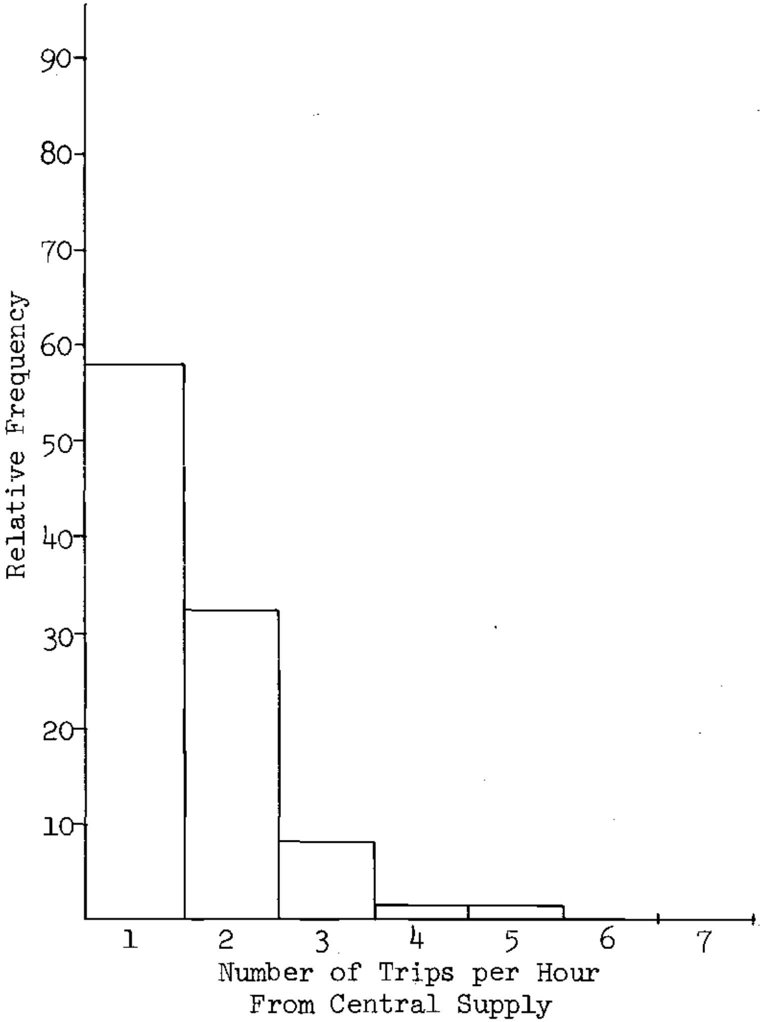


Figure 29. Trip Frequency Histograms: Central Supply - Non-professional Nursing Personnel



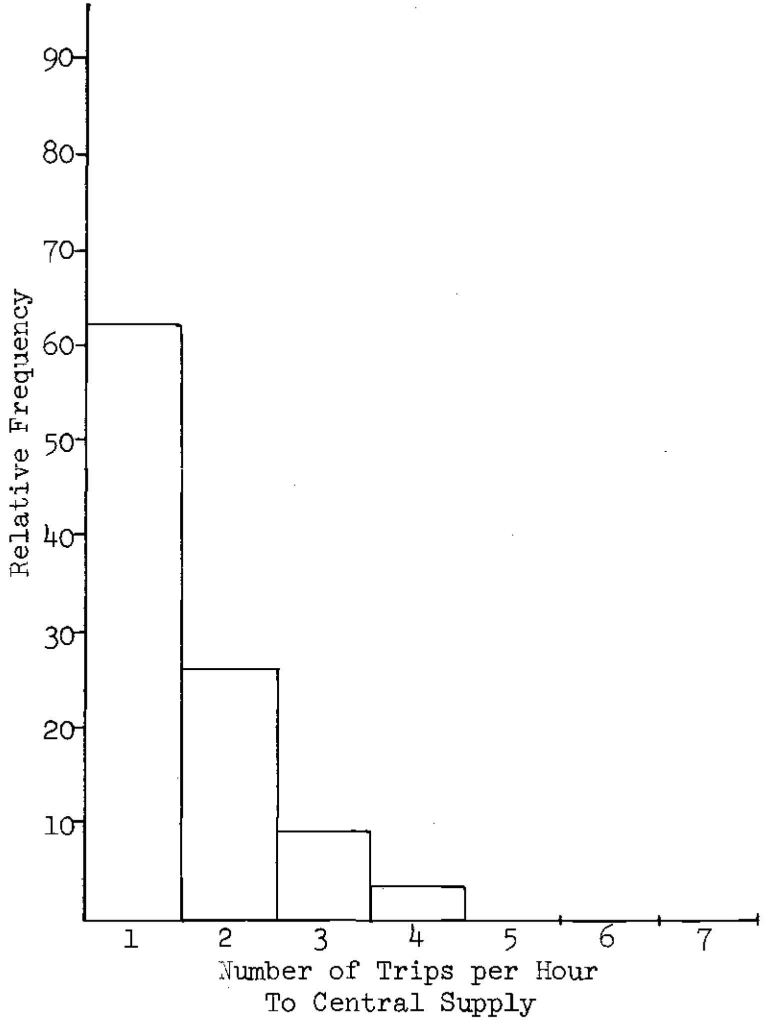


Figure 30. Trip Frequency Histograms: Central Supply - Technician Personnel

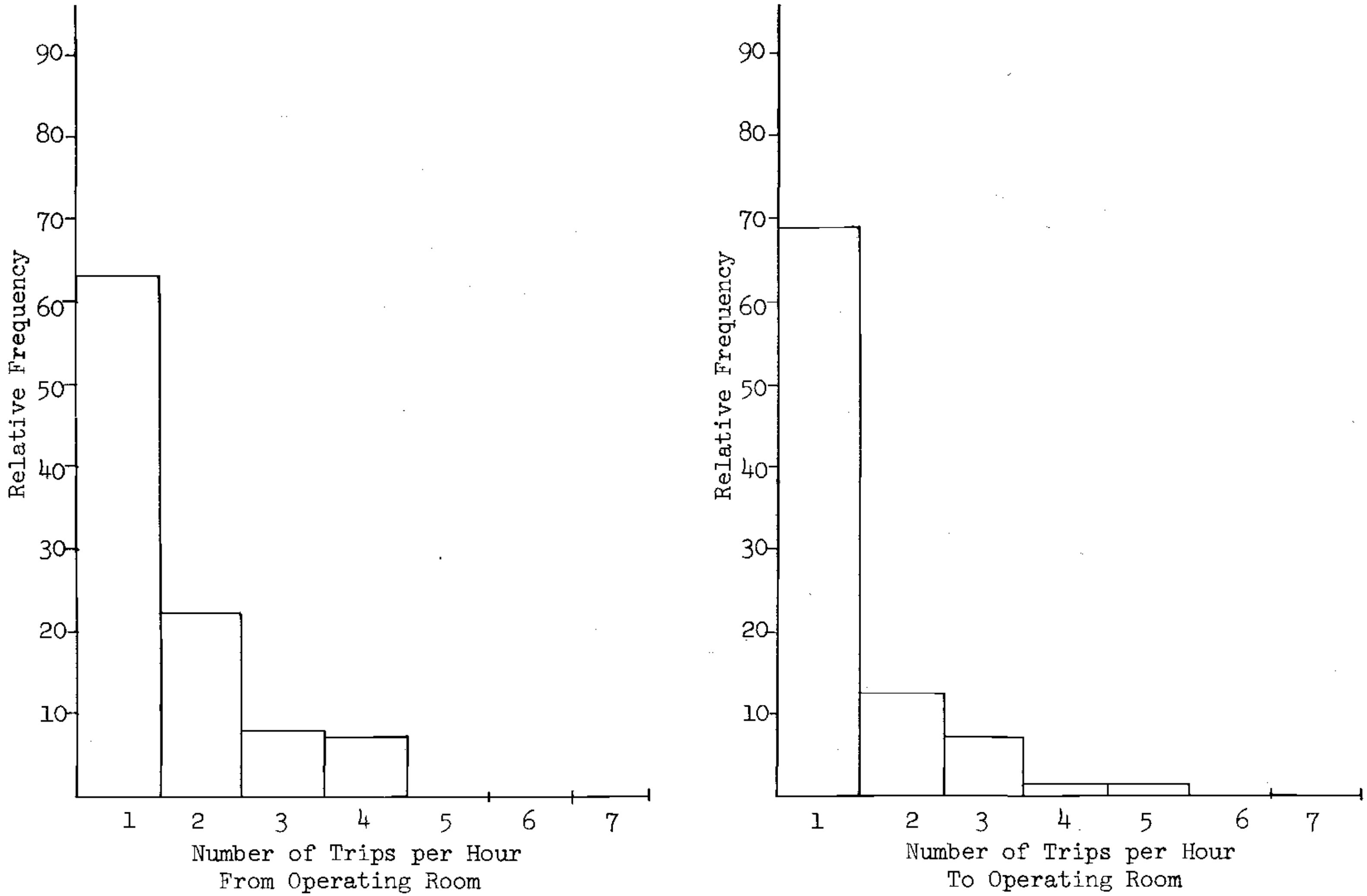
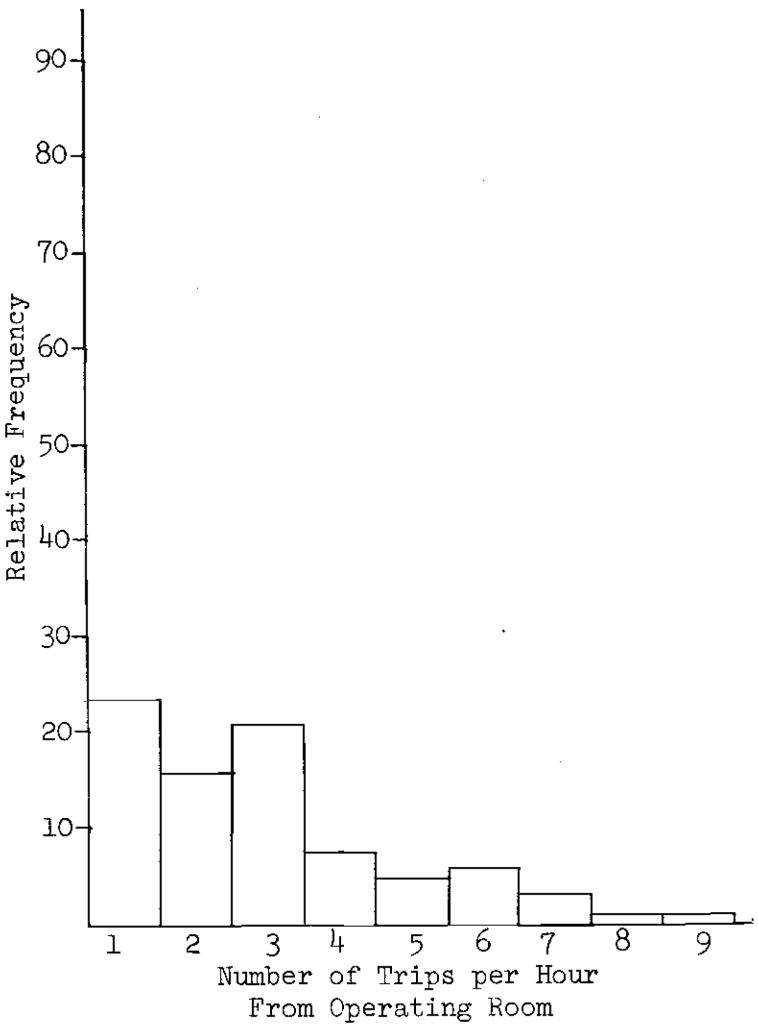


Figure 31. Trip Frequency Histograms: Operating Room - Professional Nursing Personnel



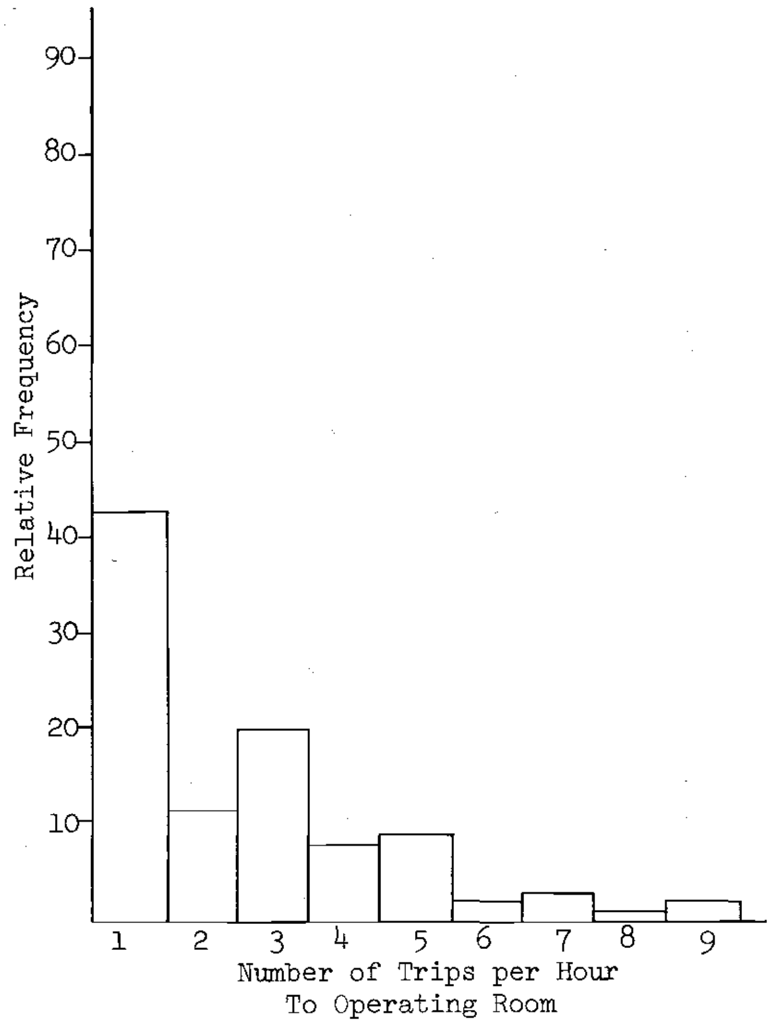


Figure 32. Trip Frequency Histograms: Operating Room - Non-professional Nursing Personnel

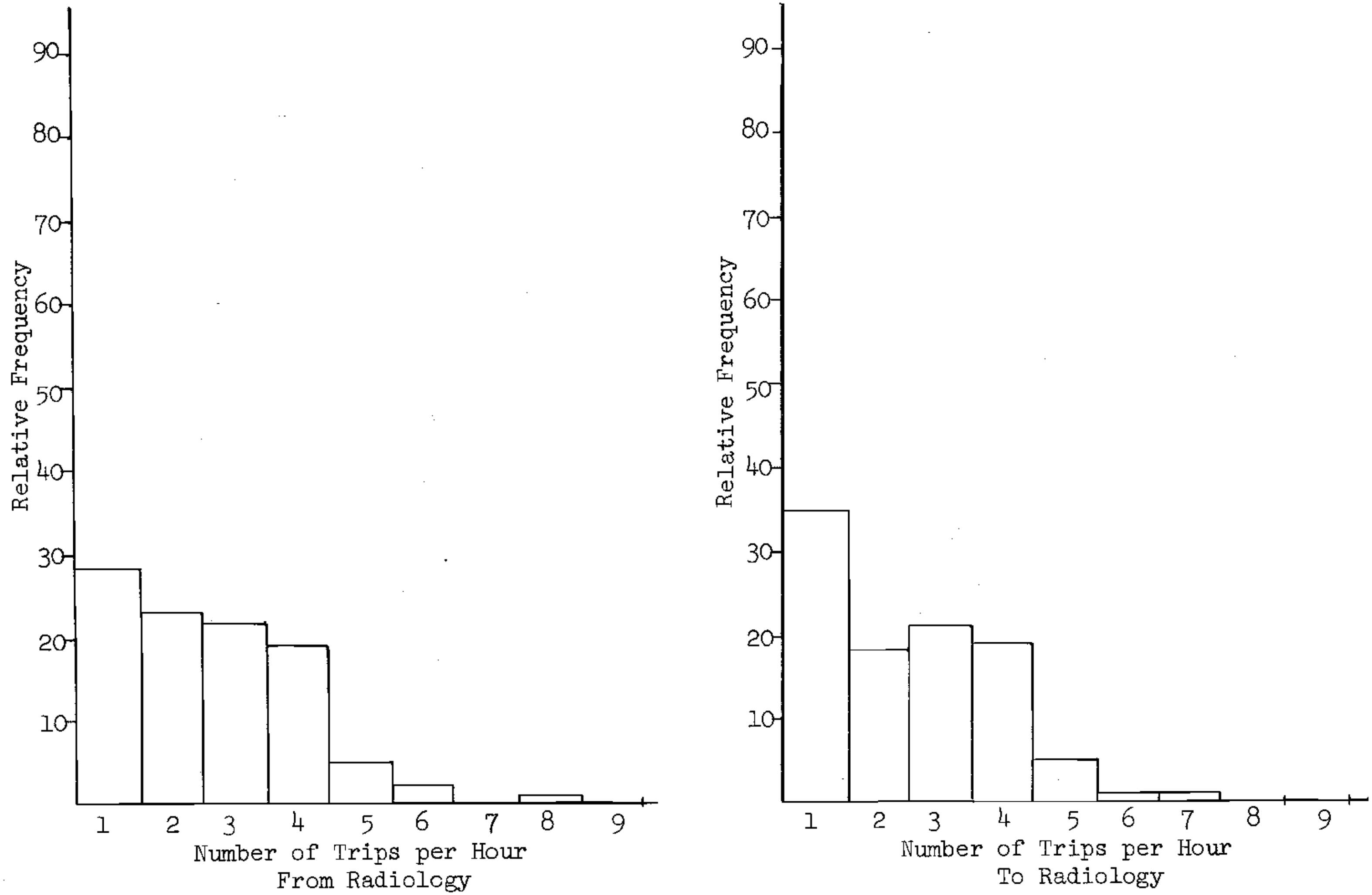


Figure 33. Trip Frequency Histograms: Radiology - Non-professional Nursing Personnel

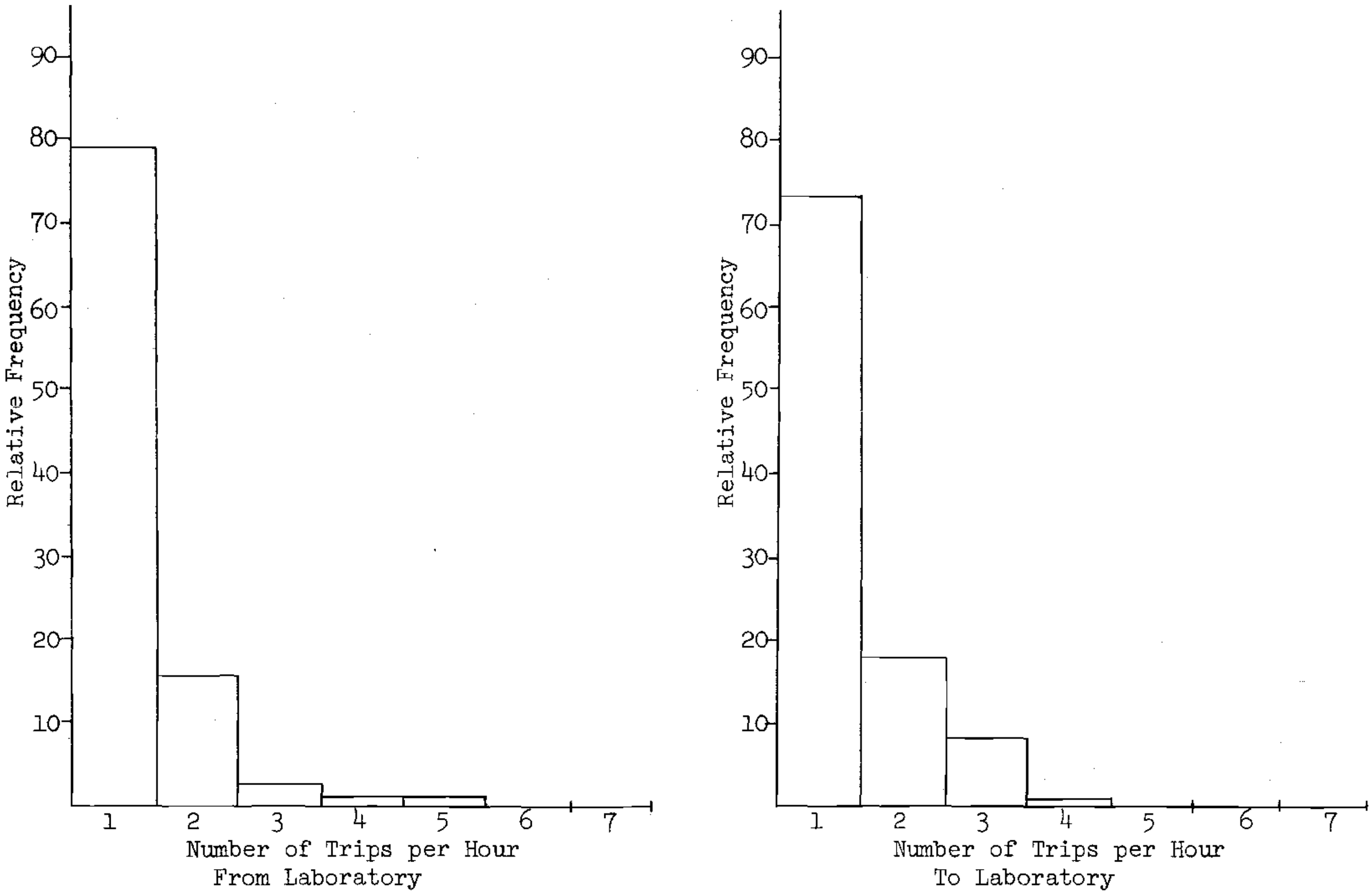


Figure 34. Trip Frequency Histograms: Laboratory - Non-professional Nursing Personnel

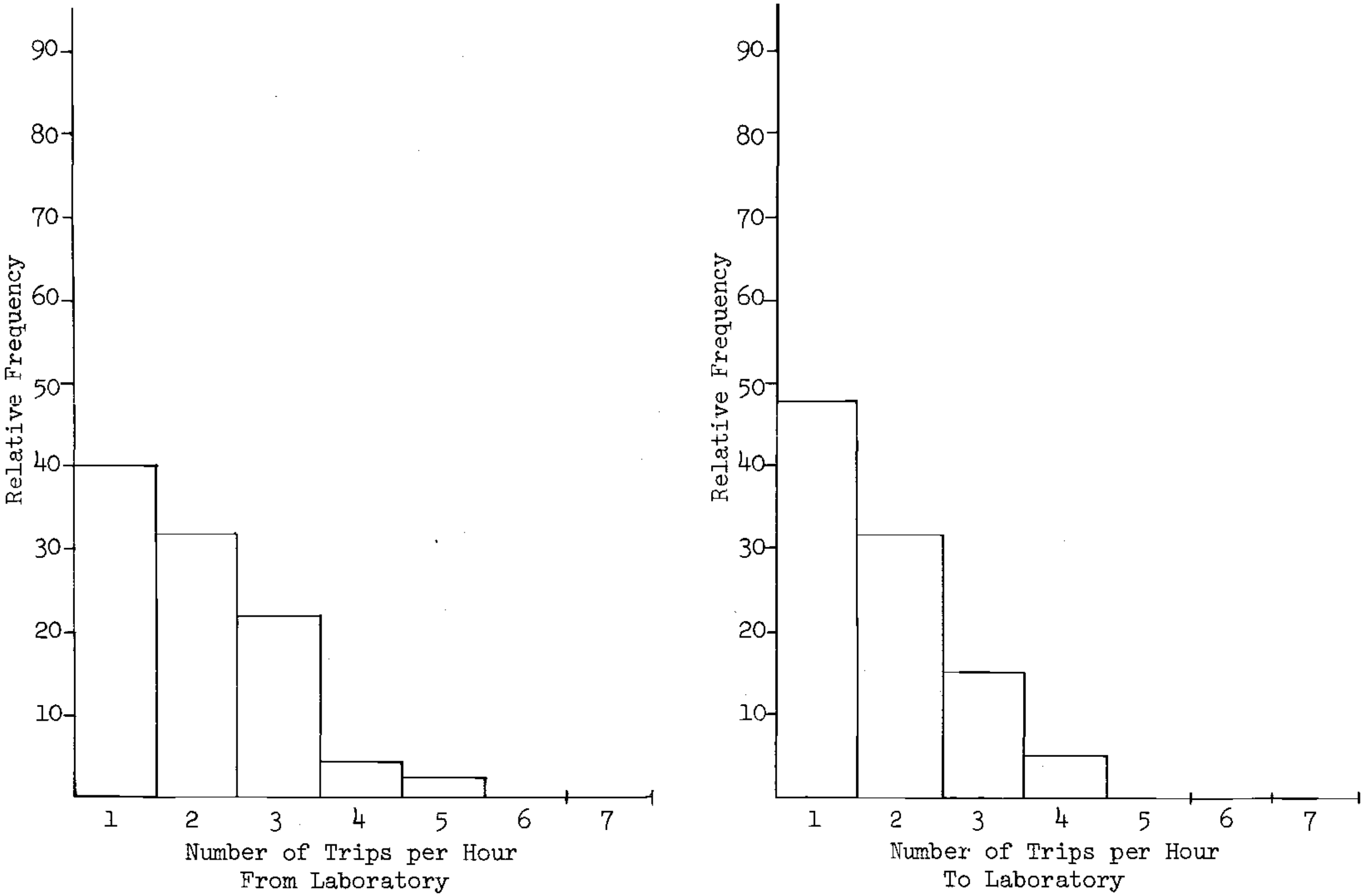


Figure 35. Trip Frequency Histograms: Laboratory - Technician Personnel

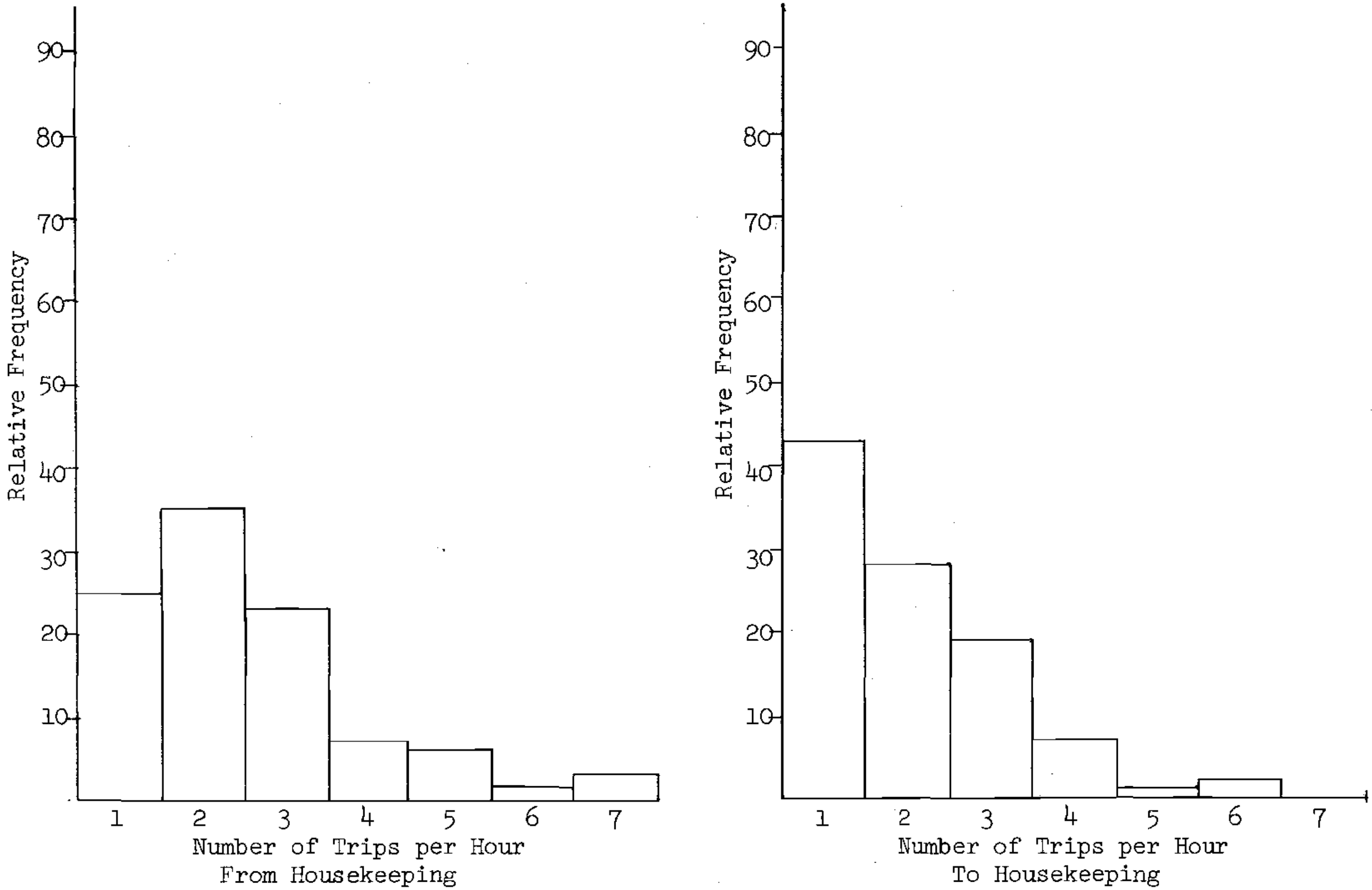


Figure 36. Trip Frequency Histograms: Housekeeping - Housekeeping Personnel

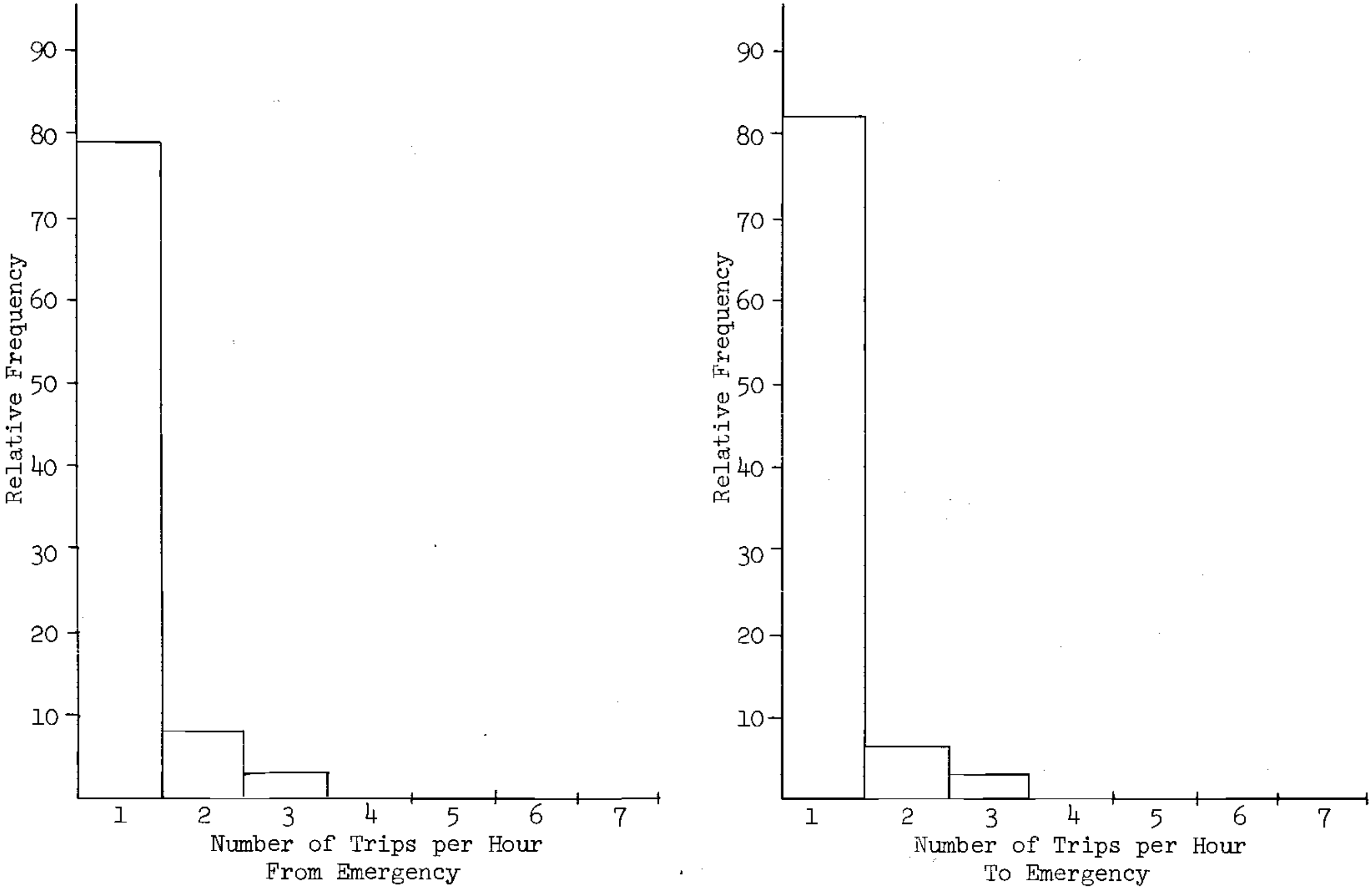


Figure 37. Trip Frequency Histograms: Emergency - Professional Nursing Personnel

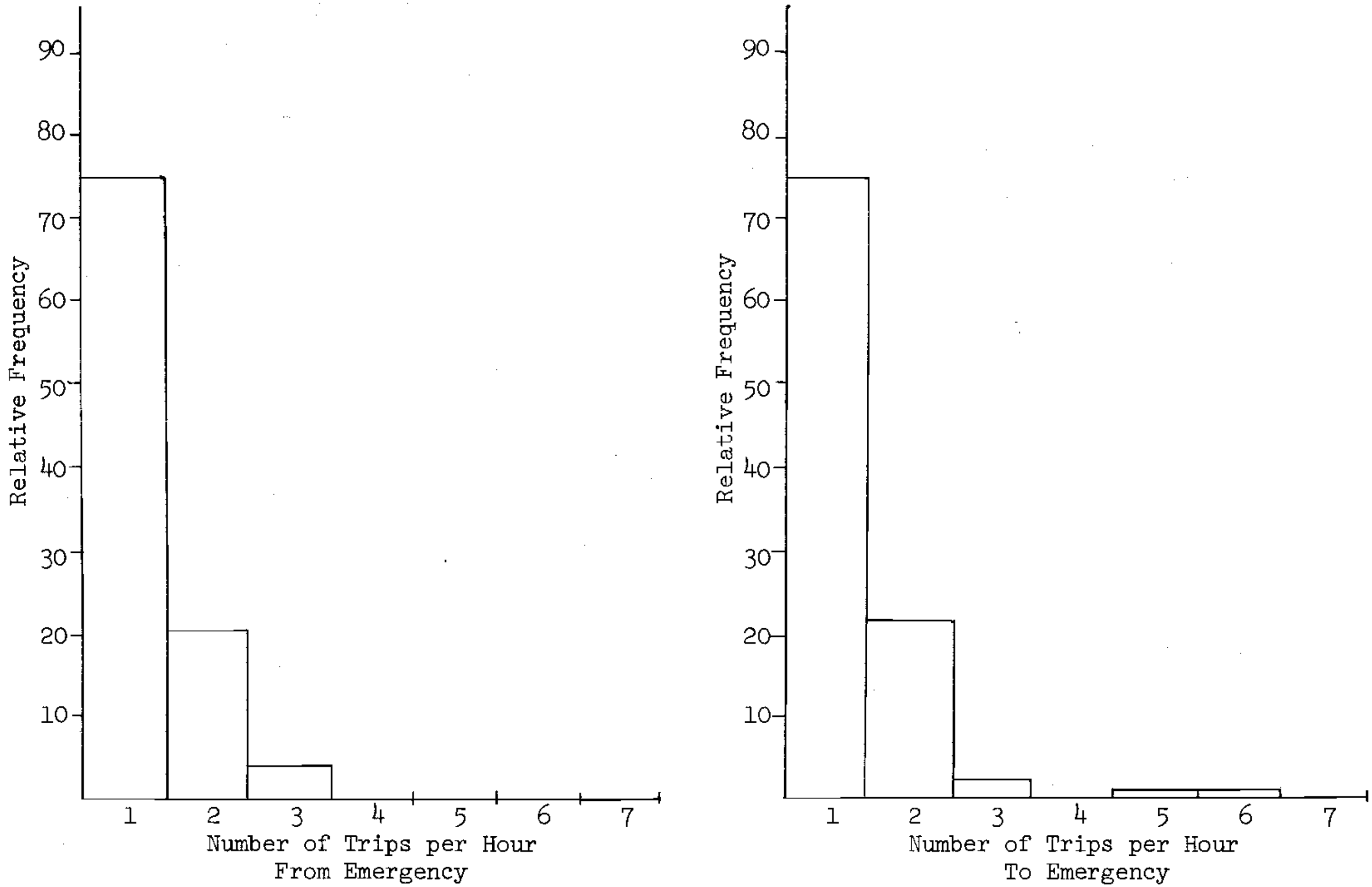


Figure 38. Trip Frequency Histograms: Emergency - Non-professional Nursing Personnel

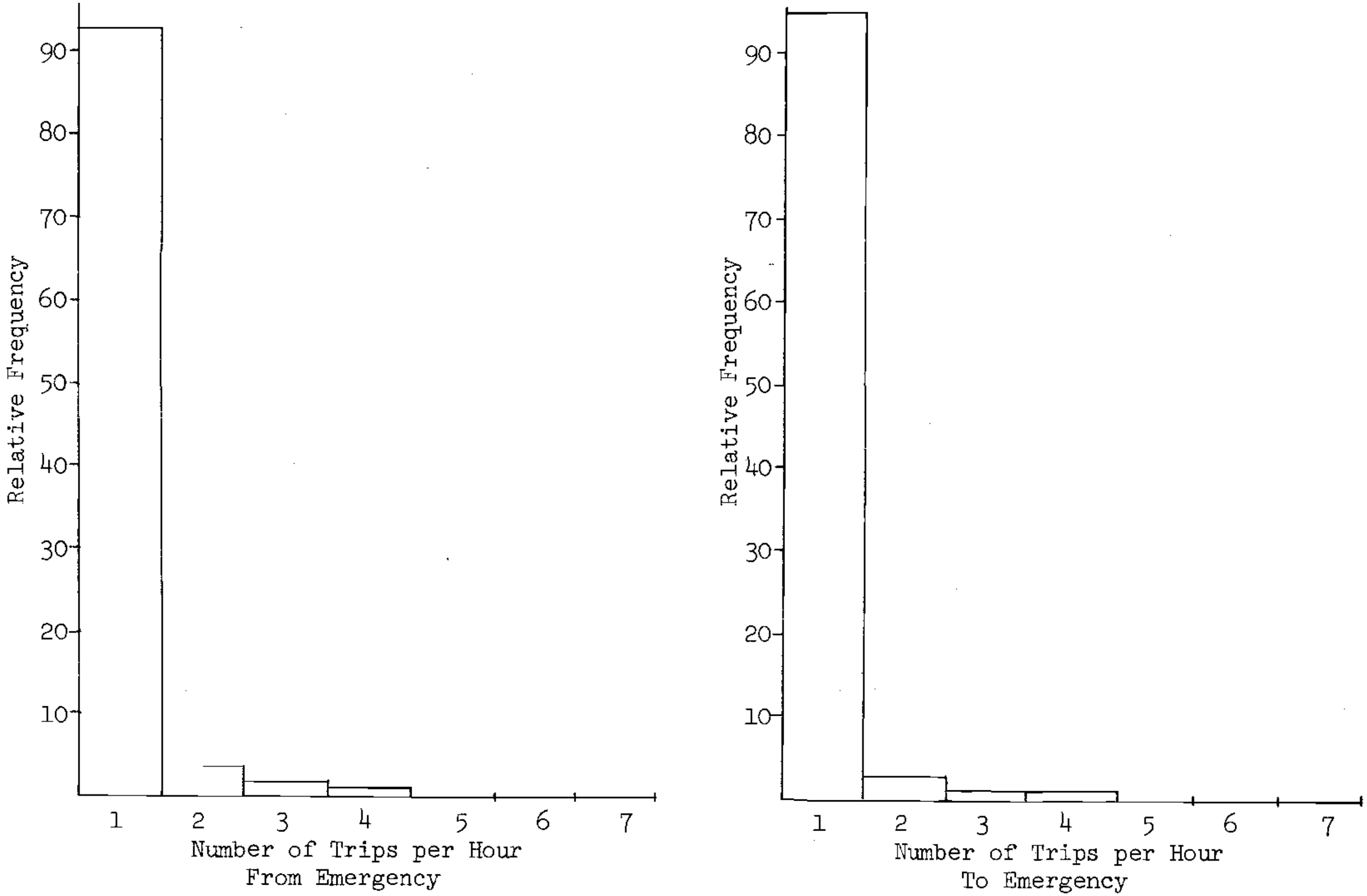


Figure 39. Trip Frequency Histograms: Emergency - Technician Personnel

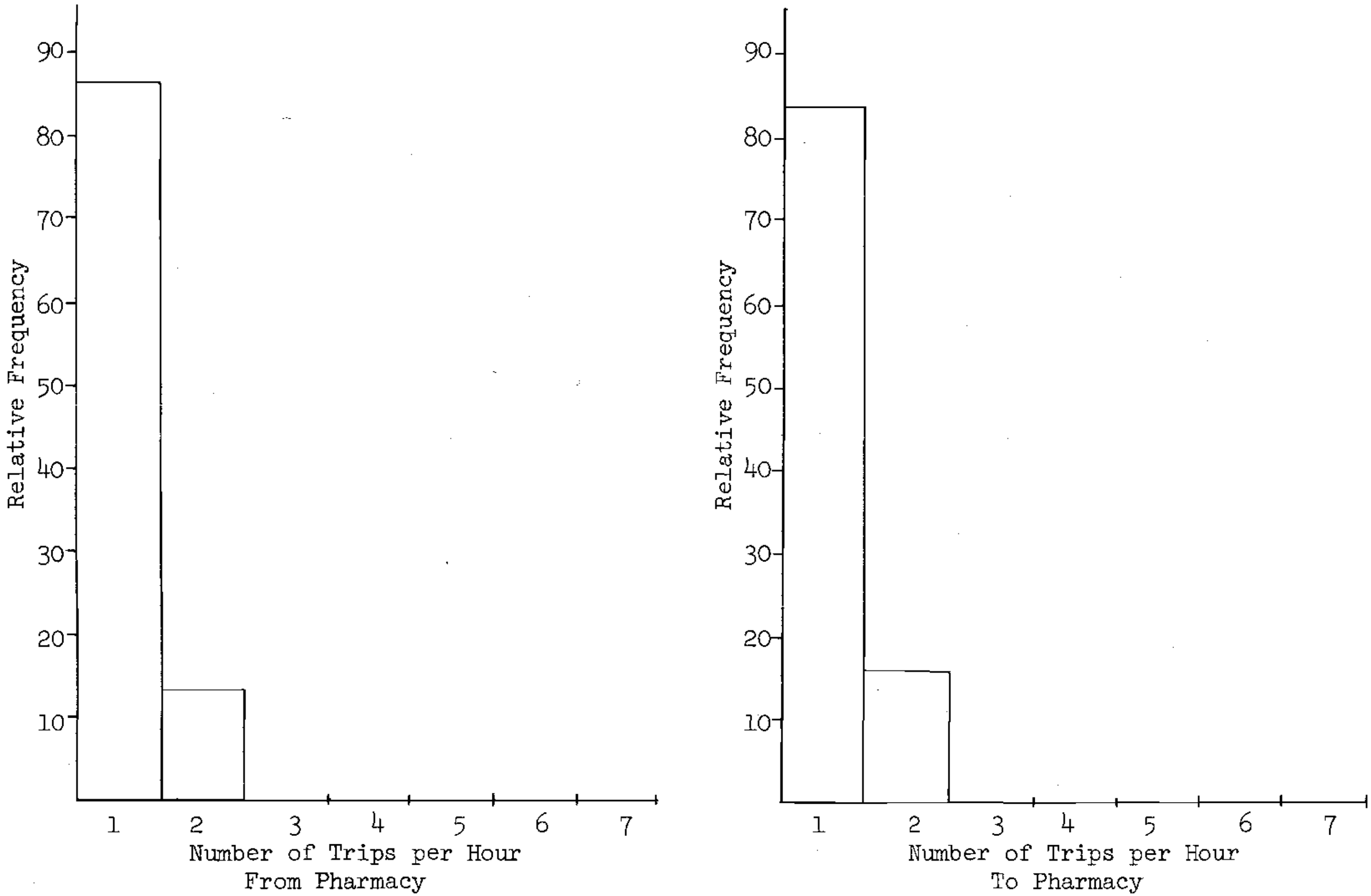


Figure 40. Trip Frequency Histograms: Pharmacy - Professional Nursing Personnel

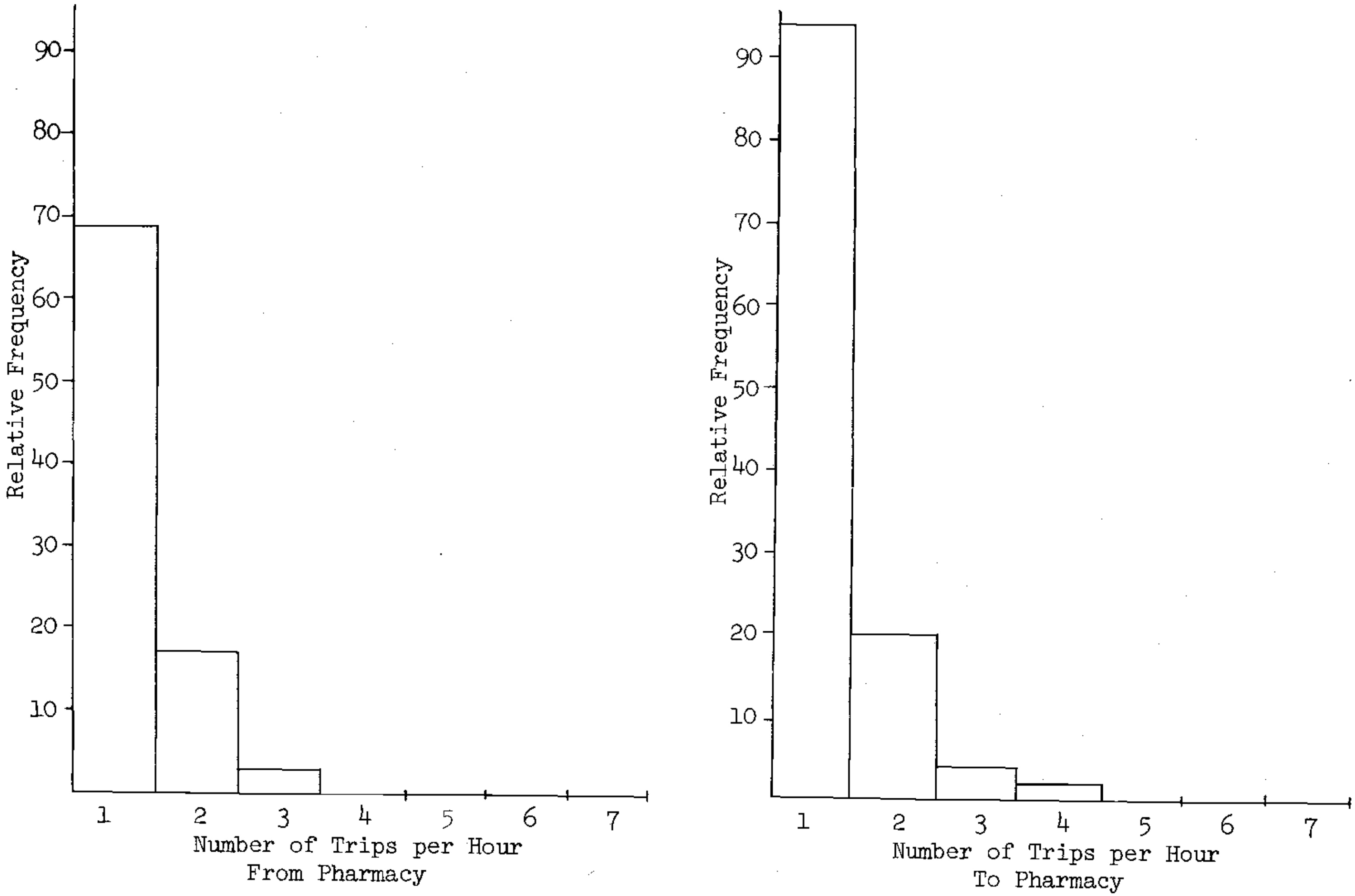


Figure 41. Trip Frequency Histograms: Pharmacy - Non-professional Nursing Personnel

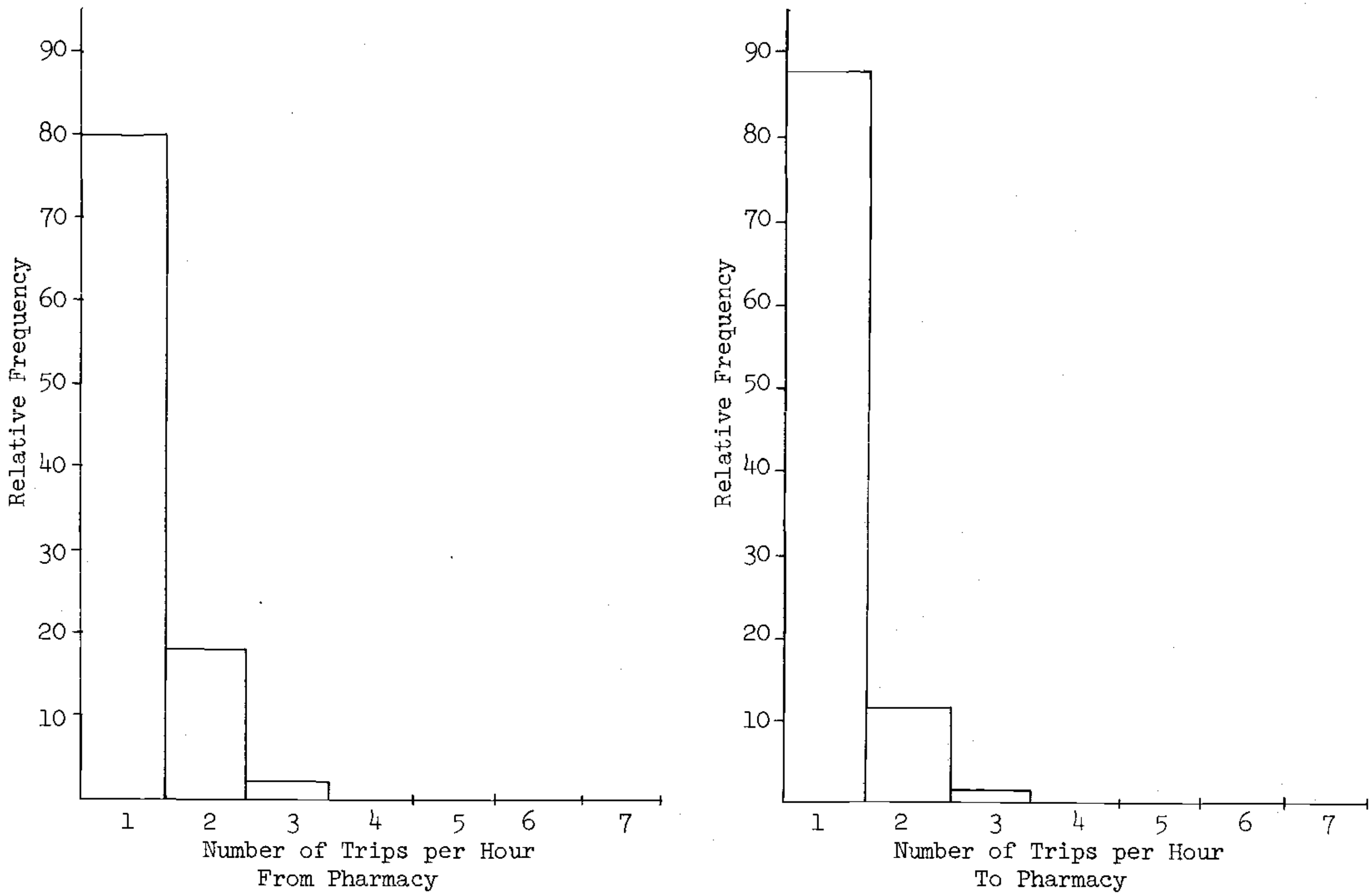


Figure 42. Trip Frequency Histograms: Pharmacy - Technician Personnel

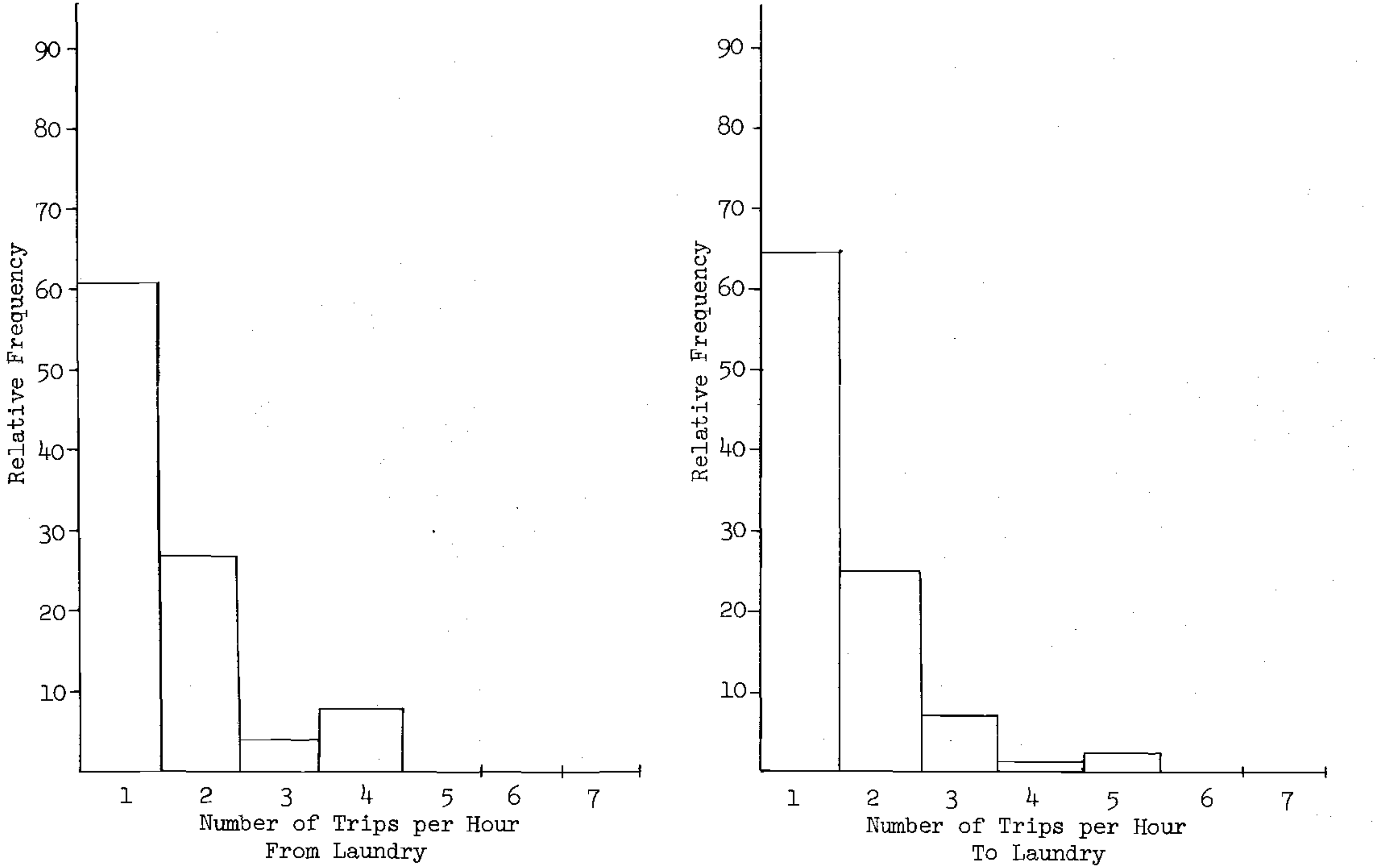


Figure 43. Trip Frequency Histograms: Laundry - Non-professional Nursing Personnel

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